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Summary of Research 1996, Department of Meteorology

Faculty of the Department of Meteorology, Naval Postgraduate School

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SUMMARY OF RESEARCH 1996

Department of Meteorology

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13. ABSTRACT (Maximum 200 words.)

This report contains summaries of research projects in the Department of Meteorology. A list of recent publications is also included which consists of conference presentations and publications, books, contributions to books, published journal papers, technical reports, and thesis abstracts.

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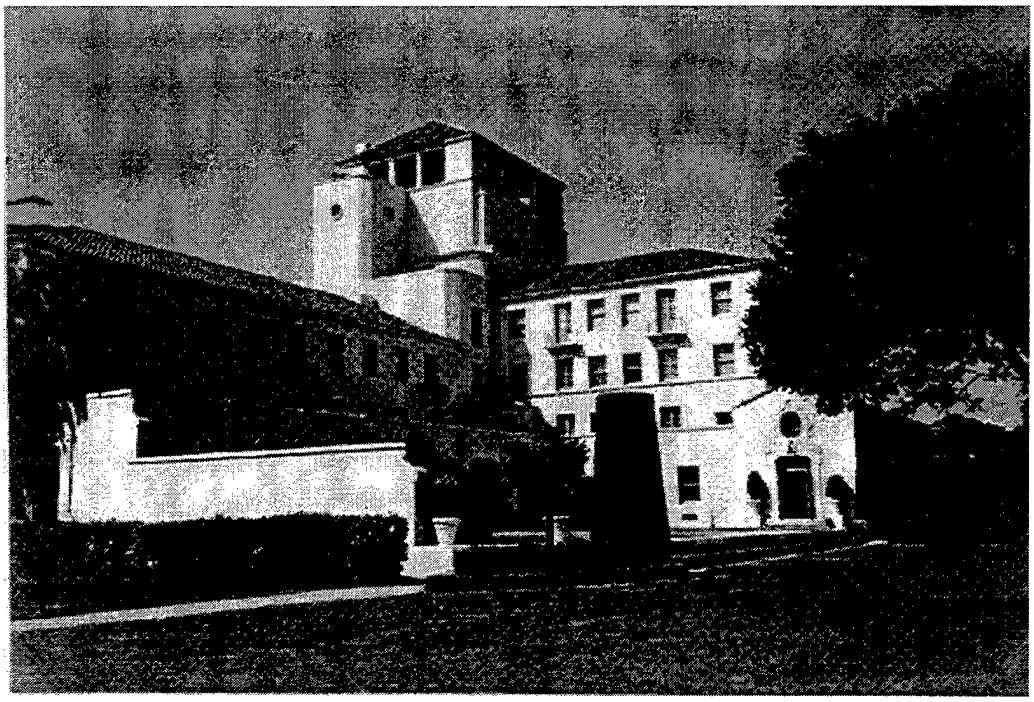
DEPARTMENT OF METEOROLOGY

CARLYLE H. WASH

CHAIR

THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to increase the combat effectiveness of US and Allied armed forces and enhance the security of the USA through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense-related challenges.



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Preface

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.
- Keep faculty on the leading edge of advances in defense-related science, technology, management and policy to ensure that the latest information is incorporated into NPS courses and curricula.
- Apply faculty and student knowledge to enhance DoN/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

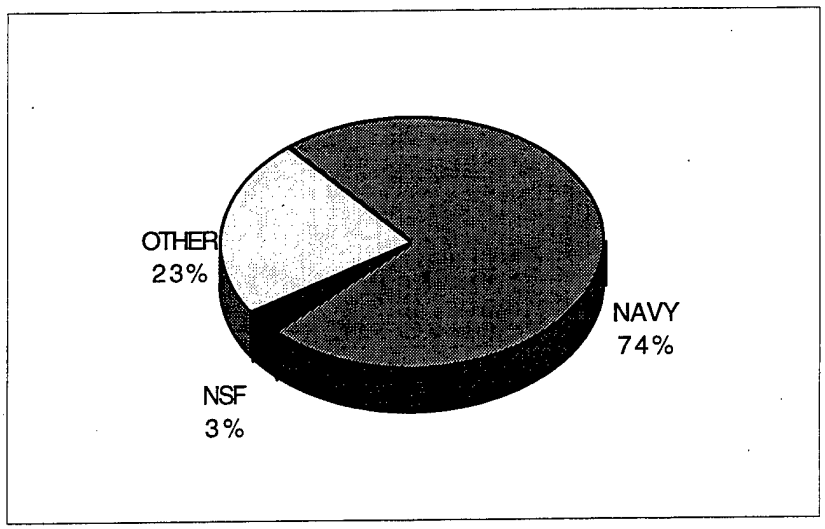
New technologies and policy changes will of course occur, necessitating changes in educational programs and stronger ties between the fleet and the support establishment. NPS must remain poised to face this challenge and to utilize emerging technologies and new policies within its curricula programs. Faculty, therefore, must stay abreast of these developments through a dynamic research program that helps fulfill the School's goals of excellence, uniqueness, and relevance.

The overall research program at NPS has three funded components. The Direct Funded Research and Institute for Joint Warfare Analysis Programs are institutionally funded within the School's operating budget. The Direct Funded Research Program is administered by the Associate Provost and Dean of Research. The Institute for Joint Warfare Analysis Program is administered by the Director of IJWA.

- The Direct Funded Research (DFR) Program provides funding to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.
- The Institute for Joint Warfare Analysis Research Program provides funding to stimulate innovative research ideas with a strong emphasis on joint, interdisciplinary areas. This funding ensures that joint relevance is a consideration of faculty research.
- The Reimbursable Research (RR) Program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The three research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

In 1996, the level of the research effort at the Naval Postgraduate School was 141 faculty workyears and exceeded 29 million dollars. Eighty percent of the research was funded by reimbursable sponsors and 20 percent was funded by the Naval Postgraduate School. Sixty-five percent of the work was performed for the Navy and the remainder was sponsored by other agencies, both DoD and non-DoD. A profile of the reimbursable program of the Department of Meteorology is provided in Figure 1:



Size of Program: $3,633K

Figure 1. Department of Meteorology - Sponsor Profile

Research at NPS is carried out by faculty in the School's eleven Academic Departments, four Interdisciplinary Groups and the School of Aviation Safety. In the pages that follow, research summaries are provided for projects undertaken by faculty in the Department of Meteorology during 1996. An overview and faculty listing are provided as an introduction. A list of publications is also included, if applicable. Abstracts for thesis advised by department faculty in 1996 complete this research summary.

Questions about particular projects may be directed to the Faculty Principal Investigator listed, the Department/ Group Chair, or the Department Associate Chair for Research. Questions may also be directed to the Research Office. General questions about the NPS Research Program should be directed to the Research Office at (408) 656-2098 (voice) or research@nps.navy.mil (e-mail).

August 1997

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DEPARTMENT SUMMARY

The Department of Meteorology has a broad yet focused research program to address scientific questions important to tactical support of both operational commanders and individual forces at sea with regard to high impact weather. For high impact weather, the Navy is turning increasingly to Rapid Environmental Assessment (REA) for tactical support, recently described our curriculum sponsor, Oceanographer of the Navy (OP-096). Of essence in Rapid Environmental Assessment is the detailed and timely Meteorology and Oceanography (METOC) characterization of a limited objective area. REA will call for sequential application of old and new techniques as operation start time (H-hour) nears. This will require enlarging the emphasis from large scale, predictive, numerical models to include "nowcasting", quick-reaction survey, direct exploitation of remote and in situ observations, innovative processing techniques for satellite data and through-the-sensor environmental measurements.

The Department's currently supported and planned research is designed to meet evolving Navy requirements and also to meet two basic motivations for METOC support: to insure the safety of the Fleet and the shore establishments in the face of adverse weather and ocean conditions; and to provide warfighters a decisive tactical edge by providing environmental parameters for weapon system performance predictions. Areas of present and for future research support are as follows:

a) Development of a unified view of the mesoscale, synoptic-scale, and large-scale environmental components of atmospheric circulations that impact Naval operations, including tropical and extratropical cyclones, coastal circulations, and upper-tropospheric circulations

b) Development and motion of extra-tropical and tropical cyclones

c) Analysis and modeling diurnal, synoptic, intraseasonal and interannual variations of tropical and monsoon weather systems

d) Formulation of methods for using remote sensing to estimate overwater coastal region radar/radio refraction conditions and aerosol/visibility conditions

e) Formulation/evaluation of physical models for near-surface turbulence and gradients affecting near-horizon optical propagation

f) Perform selection evaluation of commercial equipment to use in integrated shipboard systems that would describe electro-magnetic/electro-optical (EM/EO) conditions

g) Innovative observation and data analysis techniques and modeling method for boundary layer studies that lead to improved representation of boundary layer turbulence and clouds in global and regional models

h) Development of frontal models for application over the oceans and the land, including topography

i) Development of real-time mesoscale observing, data management, and mesoscale data assimilation techniques applicable to the coastal environment

j) Development of local modeling and mesoscale forecasting techniques to improve coastal atmospheric prediction

k) Describe air-sea-ice interactions in polar regions through *in situ* measurements.

RESEARCH FACILITIES

The Department of Meteorology has facilities for both measurement (in situ and remote sensing) of atmospheric phenomena and for numerical modeling/analyses development. In situ measurement devices are in the Marine Atmospheric Measurements Laboratory (MAML) and within a suite designed to be installed on ships of opportunity. MAML has meteorological ground stations, 405 and 915 MHz Doppler-radar wind profilers, a radiosonde system, and a SODAR, at either the NPS or at a Presidio of Monterey (POM) Annex location. Ground stations with airflow sensors and real-time transmission capabilities are located at the Point Sur Lighthouse and Point Sur Naval Base locations. A major center for interdisciplinary remotely piloted aircraft studies (CIRPAS) was established in coordination with the California Institute of Technology (CIT) with development as well as field programs in progress. The primary CIRPAS platform at this time is the Pelican aircraft. Its instrumentation for atmospheric studies has been developed with ONR funding. A shipboard system consisting of rawinsonde and sensors for airflow properties has been developed with necessary acquisition and calculation support systems. It is called the Surface-Combatant Integrated METOC Sensor (SCIMS) system. The modeling/analysis facilities are contained within the Interactive Digital Environmental Analysis (IDEA) Laboratory with 16 workstations and the Remote Sensing Laboratory with four workstations. Both laboratories provide modern computer technology, including computational and display software, and real-time data bases. Recently, Meteorology obtained a SGI multi-processor Compute Server. This allows both research and real-time mesoscale modeling of atmospheric dynamic processes, particularly for coastal regions.

SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

Commander L.E. Carr III
Russell L. Elsberry, Distinguished Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The long-term goal of the Systematic Approach concept is to improve the quantitative accuracy of official tropical cyclone (TC) track forecasts and the qualitative meteorological utility of those forecasts. The specific objectives of this phase of the long-term project are to conduct basic research to: (i) develop a TC motion meteorological knowledge base by which TC forecaster can make an effective real-time application of available and emerging basic understanding of TC motion to formulate a comprehensive, dynamically-based conceptual picture of any particular TC forecast situation, and (ii) develop a knowledge base of TC track forecast model performance in various recurring meteorological situations defined by the meteorological knowledge base in order to identify systematic model traits that can be exploited by the forecaster when formulating the official TC track forecast.

SUMMARY: The development, testing, and refinement of a comprehensive, dynamically-based meteorological knowledge base for the western North Pacific region was completed early this year and four journal manuscripts that document the results have been submitted for publication. Two of the manuscripts provide an overview of the Systematic Approach concept and its meteorological knowledge base. The remaining papers cover in more detail the development of: (i) a physically-based model for a TC tangential wind distribution with a definite measure of TC circulation extent or size, and an empirical model of beta-effect propagation speed obtained from numerical integrations initialized with the TC wind distribution model; and (ii) three distinct conceptual models of TC interaction termed direct, semi-direct, and indirect binary TC interaction based on supporting observational evidence.

Also this year a meteorological database of TC-environment classifications based on the meteorological knowledge base was extended to 7 years (1989-1995), which provided a sufficient database size to begin a systematic evaluation of the Navy Operational Global Atmospheric Prediction System (NOGAPS) track forecast traits as well as the suite of objective track forecasting techniques available to JTWC. Models were evaluated in terms of skill relative to the Climatology and Persistence (CLIPER) objective technique and in terms of along-track and cross-track error. As expected, model performance relative to CLIPER and JTWC was found to be highly situation dependent.

PUBLICATIONS:

Carr, L.E., III, and Elsberry, R.L., "Systematic and Integrated Approach to Tropical Cyclone Track Forecasting. Part I: Overview and Environmental Structure Characteristics," Weather Forecasting, 1996, (in review).

Carr, L.E., III, and Elsberry, R.L., "Models of Tropical Cyclone Wind Distribution and Beta- Effect Propagation for Application to Tropical Cyclone Track Forecasting," Monthly Weather Review, 1996, (in review).

Carr, L.E., III, Boothe, M.A., and Elsberry, R.L., "Observational Evidence for Alternate Modes of Track-altering Binary Tropical Cyclone Scenarios," Monthly Weather Review, 1996, (accepted).

Chang, C.-P., Chen, J.M., Harr, P.A., and Carr, L.E. III, "Northwestward-propagating Wave Patterns Over the Tropical Western North Pacific During Summer," Monthly Weather Review, 124, pp. 2245-2266, 1996.

Elsberry, R.L., Carr, L.E. III, Boothe, M.A., and Webb, B.H., "Systematic and Integrated Approach to Tropical Cyclone Track Forecasting. Part II: Environment Structure Characterizations of Degree of Difficulty and Track Error," Weather Forecasting, 1996, (in review).

CONFERENCE PRESENTATIONS:

Carr, L.E., III, "Progress Report on the Systematic Approach to Tropical Cyclone Track Forecasting," USPACOM Tropical Cyclone Conference, Tokyo, Japan, 27 February-1 March 1996.

Carr, L.E., III, "Interpreting Tropical Cyclone Forecast Models Using the Systematic Approach," USPACOM Tropical Cyclone Conference, Tokyo, Japan, 27 February-1 March 1996.

Carr, L.E., III, and R.L. Elsberry, "Overview of the Systematic Approach to Tropical Cyclone Track Forecasting," Interdepartmental Hurricane Conference, Miami, FL, 25-29 March 1996.

THESES DIRECTED:

Fisher, M.R., "Western North Pacific tropical cyclone wind structure and structure changes," Master's Thesis, Naval Postgraduate School, September 1996.

Webb, B.H., "Evaluation of Northwest Pacific tropical cyclone track forecast difficulty and skill as a function of environment structure," Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical cyclone motion, tropical cyclone track prediction

DEVELOPMENT OF AN EXPERT SYSTEM BASED ON THE SYSTEMATIC APPROACH TO TROPICAL CYCLONE TRACK FORECASTING

Commander Lester E. Carr III
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The long-term goals of this project, which is being pursued in collaboration with R.L. Elsberry, are the same as those for the related project entitled "Systematic Approach to Tropical Cyclone (TC) Track Forecasting" summarized elsewhere. The specific objectives of this project are to conduct exploratory research to: (i) develop a prototype expert system based on the systematic approach that methodically leads the TC forecaster through a sound forecast formulation process, exposes the forecaster to key information, prompts and assists the forecaster to make pivotal decisions, and accomplishes basic tasks for the forecaster wherever feasible; and (ii) demonstrating the feasibility of such an expert system for improving the accuracy and meteorological utility of official tropical cyclone track forecasts.

SUMMARY: This project is a new effort started in July of 1996. Initial efforts to familiarize an expert system programmer with the systematic approach concept and main components have been completed. Work is presently proceeding along the following basic lines: (i) transforming the three basic phases of the systematic approach concept into a detailed sequence of specific tasks and steps that must be accomplished to formulate a TC track forecast, (ii) identifying the particular resources and components of both the meteorological and traits knowledge bases that must be accessed either manually or with objective assistance to accomplish each task/step, (iii) deciding what tasks/steps should initially be allocated to human and machine, (iv) algorithm development for tasks to be accomplished objectively, and (v) code development.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical cyclone prediction, expert systems

MONSOON DISTURBANCES OVER THE CHINA SEAS

C.-P. Chang, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: This research is to use operational Naval regional models to study the development of the southwest monsoon over the South China Sea and East China Sea, and its effects on weather disturbances over Southeast and East Asia.

SUMMARY: In 1996 the input interface of NORAPS was changed to allow both NOGAPS and ECMWF analyses and installed an objective analysis package for conducting data impact studies. The first study using the model is to evaluate the prediction, relative to different initial data analyses, of a July 1991 Mei-Yu disturbance, which is one of the heaviest-rainfall event in East Asia and East China Sea. The result demonstrates the sensitivity of the model forecast with two different sets of initial data: the 1.125 ECMWF analysis with and without enhancement from a special Chinese radiosonde data set that was collected post-real time. In summary, the sensitivity and data impact experiments show that the difference between a high resolution global analysis such as the ECMWF and an analysis enhanced by a post-real time radiosonde data set can be significant in forecasting the intensity of the severe monsoon disturbance. A small initial error in pressure can cause a large 24 h forecast error in rainfall, but the initial wind enhancement is much less consequential as it will adjust to the pressure field. While the main impact is at the lower level, the upper tropospheric data is also important. Apparently the tropopause process plays a significant role in the development and maintenance of the severe monsoon disturbance. These results will be presented to the First WMO International Workshop on Monsoons (Chang and Yi, 1997).

Another purpose of this project is to evaluate the Navy operational models relative to their application in the tropical monsoon area. When NORAPS was applied to the East Asia - South China Sea - West Pacific region a lateral boundary problem was found in the 24 - 48 hour geopotential height and mean sea level, where grid points near the lateral boundaries show isoplethes that are parallel to the boundary. The problem normally appears in the southern and western boundaries, and sometimes in the eastern boundary as well. The problem is summarized in a interim report (Yi and Chang, 1996) and tests are being carried out with the help of NRL-Monterey scientists. We also analyzed systematic errors of NOGAPS and NORAPS from Summer 1995 to Winter 1996 when persistent weakening of the tropical upper tropospheric trough in the NOGAPS forecasts was observed. The error can be traced to a secondary circulation that is set up by a dry bias covering a broad northern tropical region extending from western North Pacific to the South China Sea, Bay of Bengal and the eastern Arabian Sea. In the meantime, wet bias appears in the southern equatorial region, particularly the Indian Ocean where strong 850 hPa cyclonic bias prevails. The results suggest that the tropical western Pacific bias is probably not directly affected by the local SST errors or the Indian Ocean systematic errors. On the other hand, NOGAPS shows a bias that tends to shift the precipitation maximum from the ITCZ and SPCZ to their poleward sides. The NORAPS errors in July 1995 can mostly be explained by boundary condition contamination from the NOGAPS errors. In January 1996 NOGAPS shows a similar pattern of systematic errors in the tropical Pacific and Indian Ocean although the magnitudes are smaller than July 1995. Significant remote influence of the Indian region errors can be detected in a Rossby-type teleconnection that propagates to the eastern North Pacific. It also exerts interesting influences on the NORAPS bias patterns over East Asia and western Pacific at 48hr forecast time. These results are reported in Chang *et al.*, 1996.

PUBLICATIONS:

Yi, Lan and Chang, C.-P., "Interim Report of NORAPS Lateral Boundary Problems in the Tropical Monsoon Region," NPS Tech Report 1996.

Chu, P.C. and Chang, C.-P., "South China Sea Warm Pool in Boreal Spring," Advances in Atmospheric Sciences (accepted) 1997.

CONFERENCE PRESENTATIONS:

Chang, C.-P., "Current Status of the U.S. and International Plan for the South China Sea Monsoon Experiment," International SCSMEX Organizing Committee Meeting, Beijing, China, November 1996.

Chang, C.-P. and Lan Yi, "Forecast of a Severe East Asian Monsoon Disturbance Using Navy's Operational Regional Model: A Sensitivity Study on Initial Data Analysis," Pre-Prints, 1997, First International Workshop on Monsoons. World Meteorological Organization, Geneva, Switzerland.

OTHER:

Chang, C.-P., Zambresky, Liana, and Reynolds, Carolyn, "A Look of NOGAPS and NORAPS Systematic Errors Over the Tropical Monsoon Region in July 1995 and January 1996," Invited Seminar, Naval Research Laboratory, Monterey, CA, 1996.

THESIS DIRECTED:

Sengelaub, Donna, "Diurnal Cycles of South China Sea Convection," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Numerical weather prediction, monsoon, South China Sea

TROPICAL MONSOON-WAVE INTERACTIONS

C.-P. Chang, Professor
R.T. Williams, Professor
Department of Meteorology
Sponsor: National Science Foundation

OBJECTIVE: This is a continuing project to study nonlinear interactions between tropical monsoon circulation and equatorial wave disturbances in the western Pacific.

SUMMARY: Further analysis of data over the region was completed and the revised manuscript showing a possible interaction between the southeastward dispersion of energy of a tropical vortex and an equatorial disturbance was published in October 1996 (Chang et al., 1996). The general behavior of nonlinear barotropic waves in a zonally varying mean flow with forcing was investigated by simulating the nonlinear evolution and equilibration of barotropic waves in a zonally inhomogeneous Bickley jet. A forcing term is included in the barotropic vorticity which makes the zonally varying jet a steady state solution to the equation. The basic jet is unstable to waves in a certain range of wavelengths. When these waves are introduced they will grow and a complicated evolution will develop as the mean flow is modified. After the model is integrated over a long time period, an equilibrated state may be found. The equilibrated state consists of a full spectrum of waves with a dominant frequency and its higher frequency modes. The equilibration depends on the five basic parameters, namely the magnitude, the width and the streamwise length of the jet, the dissipation and the beta effect. The dominant wave scale in most equilibrated states is wavenumber 1 because of the changes in the local mean flow. Except for wave 1, the dominant wave scale varies with the governing parameters. The wavelength of the dominant wave increases for wider, stronger and longer jets, for weaker dissipation and for smaller beta effect. The equilibrations are highly dependent on the parametric settings. Steady wavy, limit cycle and chaotic states are found as with other nonlinear equilibration studies. When the jet is weak but strong enough to produce waves, the equilibration behaves very smoothly. But when the jet becomes stronger, the equilibration process becomes much more complicated and the sub-region in parameter space for each type of solution becomes very irregular. When the streamwise length scale of the jet is short, wave activity occurs only for a range of medium values of the jet strength. Multiple equilibrium states are not found in this study, because all wave components must be cooperative

in their growth rather than competitive. The net local energy is mainly governed by the basic flow advection in both the linear and the nonlinear cases. In the linear case, the generation of the perturbation kinetic energy is mostly canceled by the pressure work. In the nonlinear case, the nonlinear advection of the kinetic energy plays an important role in redistributing the kinetic energy generated by the barotropic conversion. The result of this investigation has been written into a manuscript (Kwon and Williams 1997) and submitted to the Journal of the Atmospheric Sciences.

PUBLICATIONS:

Chang, C.-P., Chen., J.M., Harr P.A., and Carr, L. E., "Northwestward-Propagating Wave Patterns Over the Tropical Western North Pacific During Summer," Monthly Weather Review, 124, pp. 2245-2266, 1996.

Kwon, H.J., and Williams, R.T., 1997 "Nonlinear Equilibration of Barotropic Waves in a Zonally Non-uniform Current," submitted to Journal of the Atmospheric Sciences.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Numerical weather prediction, monsoon, South China Sea

COASTAL AEROSOL AND MARINE ATMOSPHERIC BOUNDARY LAYER (MABL) PROPERTY INVESTIGATIONS WITH REMOTE SENSING AND IN SITU DATA COLLECTION

K.L. Davidson, Professor
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Department of Meteorology
Sponsor: Naval Command Control and Ocean Surveillance Center

OBJECTIVE: To provide capability to model of near-surface optical propagation and to obtain remote sensing derived estimates of coastal marine atmospheric boundary layer properties including coastal aerosol.

SUMMARY: Atmospheric surface layer data were collected from two buoys for 3-4 week durations in Monterey Bay in March 1996 and in San Diego Bay during April 1996 and in San Diego Bay during November 1996. The surface-layer mean and turbulent data were used to interpret/evaluate application of existing models for near-horizon optical propagation. Surface layer measurements and radiosonde data, to be related to remotely sensed and in situ aerosol data, were collected on the R/V Point Sur during April 1996 period. The data were used with satellite data from NOAA polar orbiters in order to evaluate satellite sensor retrieval for coastal aerosol features. A modified algorithm for satellite sensor multispectral estimates of the marine atmospheric boundary layer depths was applied to multispectral data collected in the Variability of Coastal Atmospheric Refraction (VOCAR) and the Electro-optical Properties and Coastal Environment (EOPACE) experiments.

PUBLICATIONS:

Wash, C.H., Davidson, K.L., and Jordan, Mary S., "Multispectral Remote Sensing of Coastal Atmospheric Boundary Layer," Proceedings, Eighth Conference on Satellite Meteorology and Oceanography, pp 450-454, Atlanta, GA, 3-5 December 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Multispectral Sensing of the Coastal Atmosphere Boundary Layer," Proceedings 5th AGARD Sensor and Propagation Panel (SSP) Symposium, "Remote Sensing: A Valuable Source of Information," pp. 45-1 to 45-5, Toulouse, France, 22-25 April 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Remote Sensing of Coastal Marine Atmospheric Boundary Layer (MABL) Features," Proceedings, IGARSS96 Symposium, "Remote Sensing for the Sustainable Future," Lincoln, NE, 27-31 May 1996.

Davidson, K.L. and Frederickson, P.A., "Small-Scale Turbulence Measurements from a Buoy During MAPTIP," Proceedings, SPIE Denver 96, Special Session on "Image Propagation Through the Atmosphere," Denver, CO, 5-8 August 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Multispectral Remote Sensing of the Coastal Atmospheric Boundary Layer," 1996 Proceedings, Battlespace Atmospheric Conference, NRaD, San Diego, CA, 3-5 December 1996.

CONFERENCE PRESENTATIONS:

Wash, C.H., Davidson, K.L., and Jordan, Mary S., "Multispectral Remote Sensing of Coastal Atmospheric Boundary Layer," Eighth Conference on Satellite Meteorology and Oceanography, Atlanta, GA , 28 January-2 February 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Multispectral Sensing of the Coastal Atmosphere Boundary Layer," 5th AGARD Sensor and Propagation Panel (SSP) Symposium, "Remote Sensing: A Valuable Source of Information," Toulouse, France, 22-25 April 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Remote Sensing of Coastal Marine Atmospheric Boundary Layer (MABL) Features," IGARSS96 Symposium, "Remote Sensing for the Sustainable Future," Lincoln, NE, 27-31 May 1996.

Davidson, K.L. and Frederickson, P.A., "Small-Scale Turbulence Measurements from a Buoy During MAPTIP," SPIE Denver 96, Special Session on "Image Propagation Through the Atmosphere," Denver, CO, 5-8 August 1996.

Wash, C.H., Davidson, K.L., and Jordan, M.S., "Multispectral Remote Sensing of the Coastal Atmospheric Boundary Layer," 1996 Battlespace Atmospheric Conference, San Diego, CA, 3-5 December 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Other (Environmental Effects)

KEYWORDS: Meteorological measurement, marine atmosphere boundary layer, optical transmission, optical depth

DESIGN OF DEMONSTRATION FOR END-TO-END ENVIRONMENTAL TACAID (TDROP)

K.L. Davidson, Professor
Department of Meteorology
Sponsor: Naval Research Laboratory-Stennis Space Center

OBJECTIVE: To design a demonstration for end-to-end environmental TACAID: Tactical Dropsonde (TDROP).

SUMMARY: Current combat sophisticated sensors and "smart" weapons are critically dependent on the environmental status in the battlespace. NPS examined technical methodology with which to improve the tactical usage of the current and future operational EM/EO combat systems by improving the environmental input into the TDAs. The critical environmental parameters affecting EM/EO combat system capability are the temperature and moisture profiles over the target battlespace. A new device has been developed to provide capability to sample the EM/EO environment in the battlespace: TDROP. TDROP is a miniaturized rawindsonde that has been designed to be used in aircraft chaff launchers. The demonstration was based on TDROP which permits measuring the temperature and moisture profiles over the target area by using RECON or UVA aircraft. The radio linked data was designed to be received and forwarded to the TDA user by several means.

DoD KEY TECHNOLOGY AREAS: Sensors

KEYWORDS: Meteorological measurement, marine atmosphere boundary layer, radar refraction

NEAR-SURFACE INFRARED REFRACTION METEOROLOGICAL SUPPORT

K.L. Davidson Professor
Department of Meteorology
Sponsor: Naval Research Laboratory

OBJECTIVE: Buoy instrumentation development and data collection will be made to evaluate near temperature gradients and their influences and to achieve a buoy data-link to shore.

SUMMARY: The design effort was to match measurement requirements for IR refraction with the capabilities of procedures and techniques used successfully with the NPS buoy. Carried out in CY96 as part of an effort continuing through deployment, were: 1) Formulated requirements for IR refraction data collection, 2) Evaluated of adapting sensors and procedures used with NPS buoy to refraction studies, 3) Performed mooring design and construction to include, and 4) Deployed buoy in conjunction with NRL optical and refraction experiments.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: IR refraction, buoy, IRAMMP

SURFACE COMBATANT INTEGRATED METOC ELECTRO-MAGNETIC/ELECTRO-OPTIC SENSORS

K.L. Davidson, Professor
C.H. Wash, Professor
Department of Meteorology
Sponsor: Space and Naval Warfare Command

OBJECTIVE: To provide the Navy with the capability to obtain descriptions of EM/EO conditions from surface combatants in the Littoral Zone on the basis of *in situ* measurements through the use of state-of-the-art METOC instrumentation.

SUMMARY: This is a continuing program in which METOC systems were evaluated for use during six at-sea buoy and shipboard deployments. The deployments were designed for evaluation of measurement accuracy, acquisition adaptability and field performances. A candidate system was selected for focusing further analyses and evaluations against other components. The systems performance was shown to depend on mounting configuration. The software system for operations was being developed. Two evaporation duct modeling and measurement workshops were organized and conducted at the Naval Postgraduate School. The program supported an at-sea test of the Pennsylvania State University (PSU) Lidar Atmospheric Profile Sensor (LAPS), for one month period, on a Naval Oceanography Command operated ship.

PUBLICATIONS:

Frederickson, P.A., Davidson, K.L., and Edson, James B., "A Study of Wind Stress Determination Methods from a Ship and an Offshore Tower," Journal of Atmospheric and Oceanic Technology, (forthcoming).

THESES DIRECTED:

Baldauf, Brian K., "Evaluation of Low Altitude Rocket Dropsondes for Shipboard Atmospheric Profiling and Electromagnetic Propagation Assessment," Master's Thesis, Naval Postgraduate School, December 1996.

Cowan, G.L., "A Synoptic Prediction of Extreme Subrefraction," Master's Thesis, Naval Postgraduate School, September 1996.

Cavaleri, Gerald, " Near-surface Radar Refraction Effects on SPY-1 Performance," Master's Thesis, Naval Postgraduate School, June 1996.

DoD KEY TECHNOLOGY AREAS: Sensors

KEYWORDS: Meteorological measurement, marine atmosphere boundary layer, radar refraction

WIND/METEOROLOGICAL ANALYSES (NORCSEX)

K.L. Davidson, Professor
Department of Meteorology
Sponsor: Naval Research Laboratory-Stennis Space Center

OBJECTIVE: To calibrate/validate algorithms for interpreting physical feature or process associated with active radar (SAR and Scatterometer) measurements. To explain wind-wave coupling processes on basis of merged *in situ* and remote measured data sets.

SUMMARY: This was a continuing effort involving *in situ* measurements under the European Remote Sensing (ERS-1 and ERS-2) satellites. NORCSEX'91 and NORCSEX'95 were calibration/ validation in situ data collection efforts for both ERS-1&-2 and were conducted off the west coast of Norway; 26-29 November 1991 and 7-30 September 1995. NPS performed collaborative analyses/ interpretations of continuous measurements of the atmospheric surface layer. These were made from a ship and a buoy and regular spaced measurements to demonstrate and validate ERS-1 capabilities of detecting near surface mesoscale wind field variations. Accomplishments were to contribute to a development of the SAR wind algorithm and to verify a relationship between friction velocity and backscatter data.

PUBLICATION:

Wackerman, C.C., Rufenach, C.L. Shuchman, R.A. Johannessen, J.A. and Davidson, K.L., "Wind Vector Retrieval Using ERS-1 Synthetic Aperture Radar Imagery, IEEE Transactions on Geoscience and Remote Sensing, Vol. 34, No. 6, pp 1343-1352, November 1966.

CONFERENCE PRESENTATIONS:

Davidson, K.L., "Calibration/Validation of Surface-layer Wind Stress and Surface Waves during NORCSEX'95," Conference on Ocean-Atmosphere Meso-Scale Processes and Integrated Use of ERS-1/-2 Data, Nansen Environmental and Remote Sensing Center, Bergen, Norway, 17-20 April 1996.

THESIS DIRECTED:

Hart, James B., "An Examination of Two Synthetic Aperture Radar Wind Retrieval Models During NORCSEX'95." Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Sensors

KEYWORDS: Wind stress, marine atmosphere boundary layer, remote sensing, scatterometer, radar refraction

AEROSOL OPTICAL DEPTH RETRIEVALS WITH NATIONAL TECHNICAL MEANS DATA SETS

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to provide a real-time analysis scheme for estimating aerosol optical depth using NTM data sets. The project will validate the analysis scheme with two data sets collected in collaboration with field experiments planned for FY96 to provide aerosol properties.

SUMMARY: Achievements by this project have come in two areas. First, the NPS aerosol retrieval scheme for multiple satellite sensors including NTM has been completely rebuilt. Second, data for two field tests were collected and analysis has begun. Individual achievements and results are listed below:

- The NPS aerosol retrieval was reconfigured for AVHRR data on NOAA polar orbiting satellites, GOES-8/9 data, and NTM data. Validation of AVHRR data collected in ACE-1 was presented at the 1996 AGU Fall Meeting. The conversions were done as part of a Master's Thesis by LCDR Brian Brown (thesis completion expected June 1997). The various versions include scattering phase function and solar irradiance variations required for the varying satellite wavelength responses.
- Data was collected during the TARFOX project (July 96) including satellite data (AVHRR, GOES and NTM), aerosol physical properties (particle size, number, and composition), and aerosol optical depth (with two versions of NASA AMES sunphotometer - 6 and 14 wavelength versions). This data set was designed to provide observations at high optical depth from industrial pollution sources along the east coast of the U.S..
- NTM data collection for TARFOX was limited. Data is in-hand and has been analyzed with image processing software at NPS. Comparison with coincident satellite and aircraft measurements is in progress.
- Data was collected during aircraft flights off the West Coast of the U.S. (November 1996) to provide observations at low optical depth from background marine sources. The data set included satellite data (AVHRR, GOES and NTM), aerosol physical properties (particle size, and number), and aerosol optical depth (with the NASA AMES sunphotometer - 14 wavelength version). On one flight data was also collected with the NRL Hyperspectral imager, the NASA AVIRIS imager and the ADEOS OCTS (ocean color imager). This data may provide absolute intercalibration between all imaging systems including NTM.
- NTM data collected off the U.S. West Coast was more extensive than during TARFOX. Imagery is still in transit and will be analyzed upon receipt at NPS.
- Preparations are underway to collect data during the ACE-2 experiment in the vicinity of the Canary Islands (June-July 1997). This data set is critical to analyze sufficient high optical depth data and include data from desert dust sources. The complete set of data from clean marine conditions (U.S. West Coast), high optical depth data from pollution sources (TARFOX and ACE-2), and desert dust (ACE-2) is necessary to assure that the application of the aerosol optical depth retrieval is valid for the full range of expected aerosol sources worldwide.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Marine boundary layer, aerosol process

AEROSOL STUDIES WITH REMOTELY PILOTED AIRCRAFT (RPA)

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: This project designed the formation of a joint research effort based at NPS that would demonstrate, for the first time, the unique capabilities of RPAs for environmental measurements.

SUMMARY: The Office of Naval Research along with the NPS and California Institute of Technology (CIT) planned a set of field programs to demonstrate unique scientific research strategies and technology development with remotely piloted aircraft (RPA). In October 1992 a joint effort with ONR was initiated to investigate the possibility of using unmanned aircraft to make long-duration, low-altitude measurements of the coastal and remote marine environment. In 1996 the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) was formed. Under this proposal ONR funded NPS to prepare instrumentation for this platform in coordination with CIT. The NASA ERAST (Environmental Research Aircraft and Sensor Technology) program is now supporting NPS efforts as part of the national strategy for developing remotely piloted aircraft for scientific measurements. The aircraft has performed with onboard pilots in a series of experiments during 1996.

PUBLICATION:

Bluth, R.T., P. A. Durkee, J.H. Seinfeld, R.C. Flagan, L.M. Russell, and P. Finn, "The Center for Interdisciplinary Remotely-Piloted-Aircraft Studies (CIRPAS)," Bulletin of the American Meteorological Society, 77, 2691-2699, 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Marine boundary layer, cloud physics, aerosol process

AIRCRAFT OPERATIONS FOR THE TARFOX EXPERIMENT

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: National Aeronautic and Space Administration

OBJECTIVE: To provide aircraft support with the CIRPAS Pelican for operations of the NASA Suntracking Sunphotometer during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX).

SUMMARY: The CIRPAS Pelican performed its first experiment during TARFOX in 1996. The primary objective was to fly the new NASA Suntracking Sunphotometer during research flights out of Wallops Island, VA. In addition the Pelican made supportive aerosol measurements. In total, the Pelican made twelve research flights during TARFOX and collected data for about 40 hours of operations. Due to late arrival of the sunphotometer, 6 flights included the NASA instrument.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Marine boundary layer, aerosol process

COASTAL AEROSOL CHARACTERIZATION

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: This project will combine model and observational studies to 1) test the feasibility of integrating a full featured, process-oriented model with a meteorological model, and 2) investigate initialization schemes for numerical models using data from remote sensing and point measurements. This is a joint project between NRL, NRaD and NPS.

SUMMARY: To date the emphasis on this study has been on validation of aerosol optical depth retrievals from satellites with in situ measurements of the aerosol physical properties and integration of optical depth into model initialization schemes. In order for information about the horizontal aerosol distribution to be incorporated into a model, the information must be distributed in the vertical dimension. This requires assumptions since the satellite-retrieved value is a column integral of the aerosol properties. To first order the aerosol extinction is determined by

concentration and relative humidity. A scheme has been developed as part of this project to distribute the aerosol extinction according to the vertical distribution of relative humidity. The scheme has been compared to aircraft and radiosonde measurements of relative humidity from several experiments including the Atlantic Stratocumulus Experiment (ASTEX), the Aerosol Characterization Experiment (ACE-1), Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) and EOPACE. Information about the aerosol size distribution is also available from multispectral satellite measurements. The NPS optical depth retrieval uses this information to estimate the scattering phase function required for optical depth retrieval. The NPS approach has been compared to in situ data from the field programs described above. The results have also been compared with the NOVAM, a model of aerosol optical properties from parameterized size distributions. Early analysis indicates that the size information retrieved from satellite measurements can improve the NOVAM size distribution parameterization.

CONFERENCE PRESENTATION:

Durkee, P.A., Nielsen, K.N., Skupniewicz, C., Kapustin, V, Bates, T.S., and Quinn, P.K., "Satellite Observations of Aerosol Characteristics During ACE-1," Fall Meeting of the American Geophysical Union, San Francisco, CA, 8 December 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Marine boundary layer, aerosol process, aerosol/cloud interaction

SHIPBOARD AND SATELLITE INVESTIGATIONS OF MARINE AEROSOL PARTICLES

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: NPS in conjunction with NOAA PMEL research cruises and the ACE-1 experiment will conduct analysis of satellite observations of aerosol and cloud radiative properties.

SUMMARY: Data was collected during two cruises of the NOAA ship Surveyor. During April/May 1993, data was collected aboard the Surveyor from Tahiti to Seattle and during November/December 1993, data was collected on a reverse track from Seattle to Tahiti. This satellite data is being analyzed for aerosol properties related to shipboard measurements. Hemispheric and regional variations are evident in the data and the results will provide open ocean analysis of marine aerosol formation and transport mechanisms. Analysis is under way of the ACE-1 (Aerosol Characterization Experiment) conducted November-December 1995 south of Australia. ACE-1 is an international experiment (11 countries) designed to study the characteristics of natural and anthropogenic aerosols in the clean Southern Hemisphere. As part of the planning committee Professor Durkee coordinated the use of satellite observations for mission planning and analysis.

PUBLICATION:

Durkee, P.A., Nielsen, K.N., Skupniewicz, C., Kapustin, V., Bates, T.S., and Quinn, P.K., "Satellite Observations of Aerosol Characteristics During ACE-1," In preparation for ACE-1 Special Issue of Journal of Geophysical Research, May 1997.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality

KEYWORDS: Marine boundary layer, aerosol process, aerosol/cloud interaction

STUDIES OF THE EFFECTS OF SHIP ACTIVITY ON CLOUD PROPERTIES

Philip A. Durkee, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: This project is part of a multi-year effort to characterize the effects of ships on marine clouds. In particular, the goal is to understand the fundamental processes responsible for the formation and persistence of ship tracks - curvilinear, bright cloud features observed in near-infrared satellite imagery. The objectives during FY96 were threefold. First, analysis of the Monterey Area Ship Track (MAST) experiment was to be completed and the results of hypothesis tests were to be prepared for a special issue of the Journal of Atmospheric Science (JAS). Second, analysis of worldwide ship track characteristics was continued along with investigation of the diversity of meteorological conditions under which ship tracks can form. Finally, transition of ship track observations into an automated detection scheme and ultimately into the USCG Joint Maritime Information Element (JMIE) was to begin.

SUMMARY: The MAST Experiment was designed to test ten hypotheses on ship track formation, persistence, and required background conditions. The MAST Science Team was constructed in 1992-93 to provide the expertise to design and carry out the set of measurements required to test the hypotheses. The MAST was unique in that we were able to conduct a controlled experiment investigating a complex atmospheric phenomenon. The analysis of data and presentation of results was conducted as a team, incorporating multi-platform analysis of in situ measurements and model simulations. The formal publication of the JAS Special Issue represents a tightly focused presentation of results on a subject that has broad application of basic understanding of cloud microphysical and radiation processes to climatic impact of anthropogenic aerosol.

To date 23 publications are planned for the JAS Special Issue. Of those, 12 were directly supported by this project. One year of data was analyzed for three Pacific Ocean regional areas and two other regions identified as potentially susceptible to ship track formation. In coordination with our analysis, the U.K. Ministry of Defense is processing data from three additional regions. This data set to date includes nearly 5000 ship tracks identified in NOAA AVHRR (Advanced Very High Resolution Radiometer) imagery at 3.7mm wavelength (AVHRR Channel 3). The testing of MAST hypotheses tested has identified aerosol directly injected from the stack of the ship as the primary source of cloud modification and formation of ship tracks. In addition, the more subtle roles of aerosol-cloud interaction on drizzle suppression and CCN enhancement by gas-to-particle conversion and cloud processes have been examined.

During MAST 5 U.S. Navy ships and 31 ships-of-opportunity were observed. In addition, satellite imagery was analyzed daily to study the large scale formation characteristics of ship tracks. Correlation of known ships to ship tracks yielded over 300 cases for analysis of the physical and radiative characteristics of ship tracks. In order to insure high quality winds and ship information, 131 cases were analyzed to produce a composite picture of ship track properties. Analysis of 99 cases showed that, on average, ships are 16 km away from the head of the track as observed in AVHRR imagery. This distance corresponds to a mixing time of 25 minutes to transport the ship effluent to cloud top and disperse wide enough to brighten an AVHRR field-of-view.

Ship tracks occur in cloud-topped marine boundary layers. It is reasonable to expect that the depth of the boundary layer would affect the mixing processes and the concentration of aerosol produced by a ship. Analysis of soundings taken during MAST and SEAHUNT (Porch et al., 1995) showed a consistent reduction in ship track formation for boundary layers greater than 700m depth. This may be due to dilution of the aerosol concentration and may also be the result of internal stable layers that form more readily in deeper boundary layers and inhibit transport of the surface-based source of aerosol to the cloud.

The analysis of ship to ship track correlations also showed interesting effects of ship propulsion type and power on ship track formation. In general it was found that diesel ships that produce more aerosol than steam powered ships, produce brighter tracks that are wider and consistently more persistent. This is also true for ships of higher power output - consistent with production of more aerosol.

A worldwide set of AVHRR data has been collected for one year and is being processed. The regions of study include:

I. Western North Pacific Ocean -100% complete
II. Gulf of Alaska - 100% complete
III. Eastern South Pacific Ocean - 95 % complete

IV. Eastern North Pacific Ocean - 20% complete
V. Eastern South Atlantic Ocean - 20% complete
VI. Eastern North Atlantic Ocean - 100% complete (UK MOD)
VII. Barents Sea - in process (UK MOD)
VIII. Indian Ocean - in process (UK MOD)

Preliminary results show ship track formation in a wide variety of locations and under diverse meteorological conditions. Although layer clouds with a transport mechanism to get ship effluent to the cloud is required, ship tracks have been observed at nearly all latitudes and seasons. Not all regions have been inspected equally but it is apparent that ship tracks are observed in many oceanic regions. Most stratus regions over eastern oceans exhibit tracks and ship track occurrence increases generally with increasing latitude coincident with increased stratus cloud cover.

A project has been started to investigate both automated detection of ship tracks and the provision of ship track information to ship surveillance agencies. Mission Research Corporation (MRC) has developed an automated scheme for track detection in AVHRR imagery based on an earlier technique developed at the Naval Postgraduate School. In addition to test and evaluation of these automated detection results, MRC is coordinating with the USCG to evaluate the utility of ship track information in the Joint Maritime Information Element (JMIE).

PUBLICATIONS:

Champney, J.M., Gierens, K.M., Toon, O.B., Durkee, P.A., and Johnson, D.W., "A Numerical Investigation of the Effects of Stratiform Clouds on the Marine Boundary Layer," Journal of Atmospheric Science, 1996, submitted.

Coakley, J.A., Durkee, P.A., Nielsen, K., Taylor, J.P., Platnick, S., Albrecht, B.A., Babb, D., Chang, F.-L., Tahnk, W.R., Bretherton, C.S., and Hobbs, P.V., "The Appearance and Disappearance of Ship Tracks on Large Spatial Scales," Journal of Atmospheric Science, 1996, submitted.

Durkee, P.A., Noone, K.J., and Bluth, R.T., "The Monterey Area Ship Track (MAST) Experiment," Journal of Atmospheric Science, 1996, submitted.

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Ferek, R.J., Garrett, T., Hobbs, P.V., Strader, S., Johnson, D.W., Taylor, J.P., Nielsen, K., Ackerman, A.S., Kogan, Y., Liu, Q., Albrecht, B.A., and Babb, D., "Drizzle Suppression in Ship Tracks," Journal of Atmospheric Science, 1996, submitted.

Hindman, E.E., Porch, W.M., Hudson, J.G., and Durkee, P.A., 1994: "Ship-produced Cloud Lines of 13 July 1991," Atmospheric Environments, 28, 3393-3403.

Hobbs, P.V., Garrett, T.J., Ferek, R.J., Strader, S.R., Hegg, D.A., Frick, G.M., Hoppel, W.A., Gasparovic, R.F., Russell, L.M., Johnson, D.W., O'Dowd, C., Durkee, P.A., Nielsen, K.E., and Innis, G., "Emissions From Ships with Respect to their Effects on Clouds," Journal of Atmospheric Science, 1996, submitted.

Johnson, D.W., Taylor, J.P., Bretherton, C.S., Ferek, R.J., Garrett, T.J., Hobbs, P.V., Rand, Hr., Innis, G., Kogan, Y., O'Dowd, C., Smith, M., Noone, K.J., Pockalny, R.A., Öström, E., Flagan, R., Russell, L.M., Seinfeld, J., Durkee, P.A., Nielson, K., Hudson, J.G., King, M., Platnick, S., and Gasparovic, R., "The Impact of Ship Produced Aerosols on the Microphysical Characteristics of Warm Stratocumulus Clouds: A Test of Hypotheses 1.1a and 1.1b," Journal of Atmospheric Science, 1996, submitted.

Liu, Q., Kogan, Y.L., Lilly, D.K., Johnson, D.W., Innis, G.E., Durkee, P.A., and Nielson, K., "LES Modeling of Ship Track Formation and Its Sensitivity to Boundary Layer Structure," Journal of Atmospheric Science, 1996, submitted.

Noone, K.J., Öström, E., Ferek, R.J., Garrett, T., Hobbs, P.V., Johnson, D.W., Taylor, J.P., Russell, L.M., Flagan, R.C., Seinfeld, J.H., O'Dowd, C.D., Smith, M.H., Durkee, P.A., Nielson, K., Hudson, J.G., Pockanly, R.A., DeBock, L., Van Grieken, R., Gasparovic, R.F., and Brooks, I., "A Case Study of Ships Forming and Not Forming Tracks in Moderately Polluted Clouds," Journal of Atmospheric Science, 1996, submitted.

Noone, K.J., Johnson, D.W., Taylor, J.P., Ferek, R.J., Garrett, T., Hobbs, P.V., Durkee, P.A., Nielsen, K., Platnick, S., King, M.D., Öström, E., O'Dowd, C., Smith, M.H., Russell, L.M., Flagan, R.C., Seinfeld, J.H., DeBock, L., Van Grieken, R., Hudson, J.G., Brooks, I., Gasparovic, R.F., and Pockalny, R.A., "A Case Study of Ship Track Formation in a Polluted Marine Boundary Layer," Journal of Atmospheric Science, 1996, submitted.

Platnick, S., Durkee, P. A., Nielsen, K., Taylor, J. P., Tsay, S.-C., King, M. D., Ferek, R. J., and Hobbs, P. V., "The Role of Background Cloud Microphysics in Ship Track Formation," Journal of Atmospheric Science, 1996, submitted.

Porch, W.M., Kao, C.-Y., Buckwald, M.I., Unruh, W.P., Durkee, P.A., Hindman, E.E., Hudson, J.G., "The Effects of External Forcing on the Marine Boundary Layer: Ship Trails and a Solar Eclipse," The Global Atmosphere and Ocean System, 3, pp. 323-340, 1995.

Porch, W., Babb, D., Borys, R., Durkee, P., Fairall, C., Gasparovic, R., Hooper, W., Hindman, E., Hudson, J., and Nielsen, K., "Characterization of Ship Tracks from Surface-based Platforms," Journal of Atmospheric Science, 1996, submitted.

THESIS DIRECTED:

Tessmer, S., "Analysis of Shiptrack Persistence with *in situ* Cloud Measurements and Satellite Retrieved Reflectance," Master's Thesis, Naval Postgraduate School, March 1996.

DoD KEY TECHNOLOGY AREAS: Sensors, Environmental Quality, Surface/Under Surface Vehicles - Ships and Watercraft

KEYWORDS: Marine boundary layer, ship effects, cloud physics, aerosol process, aerosol/cloud interaction

TROPICAL CYCLONE MOTION STUDIES

Russell L. Elsberry, Professor
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Jeng-Ming Chen, Research Assistant Professor
Department of Meteorology
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVES: The long-term goal of this continuing project is to improve the prediction of tropical cyclone track and structure so that warnings to the Fleet units afloat and ashore are optimized. Specific objectives include: (1) Improve the specification of the initial outer wind structure in the tropical cyclones for numerical models and for forecaster understanding of the tropical cyclone-environment structure, and for use in surface wind warnings; (2) Improve understanding of the interaction of a tropical cyclone with mountainous topography that will cause upstream track deflections, and thus change the landfalling location; and (3) Improve tropical cyclone track prediction by demonstrating that objective aids tailored to specific synoptic pattern/region combinations provide better guidance than existing objective aids.

SUMMARY: An angular momentum model proposed by Carr and Elsberry has been applied to define the outer tangential wind profile, and three methods have been used to estimate the cyclonic wind extent in one of four size categories (Fisher 1996). Based on the JTWC-specified wind radii during the intensification phase of western North Pacific tropical cyclones, 60% had continual growth, 24% contracted, and 16% maintained relatively constant in cyclonic wind extent. During the decaying phase, 65% decreased, 29% had continued growth, and 6% had a relatively

constant cyclonic wind extent. A satellite-based method of estimating extent generally agreed with the wind radii estimate, except that more large tropical cyclones were specified. A multi-quadric interpolation analysis of composited wind observations produces objective estimates of wind radii, and thus the outer wind structure, for larger tropical cyclones. A combination of the multiquadric approach and the satellite method is recommended to improve the JTWC wind radii specifications.

The full physics, multi-level Naval Operational Regional Atmospheric Prediction System numerical model is used as a control with a tropical cyclone adjacent to short versus long topography, and then the vertical resolution is systematically degraded to a single, free-tropospheric layer and latent heat release and the frictional boundary layer are eliminated to understand the physical mechanisms that change the upstream track deflections. The longer topography consistently generates larger southward deflections of an adjacent (to the east) tropical cyclone vortex than does the shorter topography. Reducing the vertical resolution to one free-tropospheric layer also results in larger southward deflections, and forces the tropical cyclone to remain vertically coupled. In the adiabatic model sensitivity test, the interaction with the topography is delayed, is weaker, and results in smaller southward track deflections. In all cases, the horizontal vorticity advection that is introduced when the tropical cyclone vortex is deformed by the interaction with the topography is the primary physical mechanism, rather than column stretching as the flow is forced over the topography (Hirschberg, Liou, and Elsberry 1996).

The synoptic pattern/region assignments for western North Pacific tropical cyclones during 1985-1998 are used to test the improvement of a synoptic-based CLIPER over the operational CLIPER technique, and then append a composited post-transition track to improve track predictions during environment structure transitions. For a CLIPER equation set derived and tested with tropical cyclones in the Standard/Dominant Ridge pattern/region for the entire 72 hr forecast interval, the improvement relative to the operational CLIPER is 13% after only 12 hr and increases to 24% at 72 hr. For a modified CLIPER approach to address the short-term track variability and smaller sample sizes of the Poleward/ Poleward-oriented pattern/region, the improvement relative to the operational CLIPER is 14% after 12 hr, and is only 11% at 72 hr. Given a perfect knowledge of the type and timing of two transitions, the appending of a composited post-transition track can lead to about 50% reduction relative to the 72 hr operational CLIPER errors if the transition occurs early in the forecast interval. This results is a validation of the environment structure change focus of the systematic approach (Elsberry, Chen, Boothe, and Carr 1996).

PUBLICATIONS:

Elsberry, R.L., Chen, J.-M., Boothe, M.A., and Carr, L.E., III, 1996: "A Climatology and Persistence Tropical Cyclone Track Prediction Technique for Specific Synoptic Situations," 1996, (submitted).

Hirschberg, P.A., Liou, C.-S., and Elsberry, R.L., "Sensitivity of Tropical Cyclone-topography Interaction Simulations to Orography Cross-track Scale, Vertical Resolution, and Diabatic Heating," 1996, (submitted).

THESIS DIRECTED:

Fisher, M., "Western North Pacific Tropical Cyclone Wind Structure and Structure Changes," Master's Thesis, Naval Postgraduate School, September 1996.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical cyclone track prediction, tropical cyclone wind structure, topography-cyclone interaction

SCIENTIFIC DATA IMPACT STUDY OF NASA SCATTEROMETER (NSCAT) OBSERVATIONS NEAR TROPICAL CYCLONES

Russell L. Elsberry, Professor
Department of Meteorology
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: A data impact study of the NASA scatterometer (NSCAT) surface wind observations near tropical cyclones will be performed in conjunction with J. Goerss and J. Hawkins of the Naval Research Laboratory-Monterey.

SUMMARY: This is a new research project following the launch of the NSCAT instrument aboard the NASA-Japan ADEOS satellite on 16 August 1996. The first sets of surface wind speeds have been received and overlaid on satellite infrared imagery for quality control. Following calibration and validation revisions, the NSCAT observations will be inserted in the Navy Operational Global Atmospheric Prediction System and the impact on tropical cyclone track predictions will be assessed.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Tropical cyclone surface winds, NASA scatterometer evaluation, tropical cyclone track prediction

ATMOSPHERIC FORCING DURING THE ANZONE WINTER FLUX EXPERIMENT (ANZFLUX)

P.S. Guest, Meteorologist
K.L. Davidson, Professor
Department of Meteorology
Sponsor: National Science Foundation

OBJECTIVE: This was the second year of a three year program to characterize air-ice-sea interactions in the Weddell Sea.

SUMMARY: Several studies have been completed or are underway based on results obtained from the summer 1994 ANZFLUX field program. The variations and the mean value of the total surface heat flux were primarily determined by the longwave radiation balance during the ANZFLUX project. The longwave radiation balance, in turn, was mostly controlled by the amount of clouds. Despite intense storm activity, cloud conditions, not surface wind speed nor air temperature, dominated the direct thermodynamic forcing of the atmosphere on the ocean.

A paper was submitted to the Journal of Geophysical Research, which analyzes radiation during the winter in the Weddell Sea. Topics include factors affecting the surface albedo, surface IR emissivity and downward shortwave and longwave radiation. Previously published and newly-derived empirical formula for predicting downward radiation are compared with the ANZFLUX data. A numerical radiation model initialized with the rawinsonde soundings will be used to interpret the radiation results.

Future projects include analyzing sonic anemometer data to determine drag coefficients and sensible heat transfer coefficients during the ANZFLUX period. There will be a collaboration with other ANZFLUX researchers on understanding the vertical transfer of heat and momentum between the atmosphere, ice, ocean mixed layer and pycnocline layers. In addition collaborative studies on regional air/ice/ocean heat budgets in the Weddell Sea during winter are planned.

PUBLICATIONS:

Guest, P.S., "Surface Heat Fluxes in the Eastern Weddell Sea During Winter," Antarctic Journal of the United States, (in press).

Guest, P.S., "Surface Radiation Conditions in the Eastern Weddell Sea During Winter," Journal of Geophysical Research, (submitted).

Guest, P.S., "Studies of Surface Heat Fluxes and Atmospheric Boundary Layer Physics Over Sea-ice Regions," Antarctic Global Change Research, Newsletter of the SCAR Global Climate Change Programme, Number 1, April 1996 SCAR Global Climate Change Programme Office, Tasmania, Australia.

McPhee, M., Ackley, S., Guest, P., Huber, B., Martinson, D., Morison, J., Muench, L., Padman, R., and Stanton, T., "The Antarctic Zone Flux Experiment," Monthly Weather Review, 77, June 1996, pp. 1221-1232.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Weddel Sea, heat flux, wind stress, air/ice ocean interactions, marine atmospheric boundary layer

ATMOSPHERIC FORCING OF ICE AND OCEAN IN ARCTIC REGIONS

P.S. Guest, Meteorologist
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this study is the publication of surface sensible and latent heat flux statistics for the Nordic Sea area, with emphasis on the maximum-flux regions near the ice edge. The statistics are based on *in situ* measurements by the PI and associates.

SUMMARY: Heat fluxes were less than reported in a recent article. This has important implications for understanding oceanographic processes such as deep convection. The results of this and related studies are in various stages of publication.

PUBLICATIONS:

Rasmussen, E.A., Guest, P.S., and Davidson, K.L., "Synoptic and Mesoscale Features Over the Ice-covered Portion of the Fram Strait in Spring," Journal of Geophysical Research, (in press).

Guest, P.S., "Surface Turbulent Heat Fluxes in the Nordic Seas During Winter," Journal of Geophysical Research, (submitted).

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Heat flux, air/ice ocean interaction

DATA ASSIMILATION AND MODEL SIMULATIONS IN THE CALIFORNIA CURRENT

R.L. Haney, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The broad objective of this research is to contribute to the development of a reliable modeling capability for eastern boundary current regions. Toward this end data assimilation and model simulation studies of the California coastal ocean region will be carried out. The effort will build on the results of previous NOMP research, and it will lead to a comprehensive understanding of the mesoscale dynamics of eastern boundary current regions and the important issues involved in modeling such regions. It will also contribute directly to FNMOC's efforts to develop an operational modeling/forecast capability for the California coastal oceans.

SUMMARY: *In situ* hydrographic data and remotely sensed sea surface temperature data were assimilated into a primitive equation model in order to diagnose and describe the kinematics and dynamics of a closed cyclonic eddy observed off Point Arena, California, in May 1993. Progress has also been made in verifying digital filter initialization

(DFI) as a diagnostic tool in physical oceanography. Finally, studies were completed on the general three dimensional structure and circulation in the Alboran Sea, shear and curvature vorticity and its application in the ocean, a generalized omega equation for diagnosing the vertical velocity in the ocean and its application, and an ocean jet impinging on a coastline. The results of these studies are in various stages of publication and presentation as listed below.

PUBLICATIONS:

Haney, R.L, Viudez, A., and Tintore, J., "Circulation in the Alboran Sea as Determined by Quasi-synoptic Hydrographic Observations. Part 1. Three-dimensional Structure of the Two Anticyclonic Gyres," Journal of Physical Oceanography, 26, 684-705, 1996.

Haney, R.L., Viudez, A., and Tintore, J., "Circulatioin in the Alboran Sea as Determined by Quasi-synoptic Hydrographic Observations. Part 2. Mesoscale Ageostrophic Motion Diagnosed through Density Dynamical Assimilation," Journal of Physical Oceanography, 26, 706-724., 1996

Haney, R.L., and Viudez, A., "About the Nature of the Generalized Omega Equation," Journal of Atmospheric Science, 53, 787-795.

Haney, R.L., and Viudez, A., "On the Shear and Curvature Vorticity Equations," Journal of Atmospheric Science, 53, 3384-3394.

Haney, R.L., "On the Relative Vorticity of the Atlantic Jet in the Alboran Sea," Journal of Physical Oceanography, (with A. Viudez) in press, 1997.

Haney, R.L., "The Deflection and Division of an Oceanic Baroclinic Jet by a Coastal Boundary. A Case Study in the Alboran Sea," Journal of Physical Oceanography, (with A. Viudez) in press, 1997.

Haney, R.L., "Kinematics and Dynamics of a Cyclonic Eddy off Point Arena, California," Journal of Physical Oceanography, (with R. Chumbinho and S. Ramp) submitted, October 1996.

CONFERENCE PRESENTATION:

Haney, R.L., 1996, "A Model Simulation of Wind and Boundary Forced Jets and Eddies in the Coastal Ocean off of Central California," AMS Conference on Coastal Oceanic and Atmospheric Prediction, Atlanta, GA, 28 January-2 February 1996.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Alboran Sea, cyclonic eddy

ATMOSPHERIC COMNAVMETOCCOM INDEPENDENT MODEL REVIEW PANEL (CIMREP)

Robert L. Haney, Professor
Carlyle H. Wash, Professor
Department of Meteorology
Sponsor: Naval Meteorology and Oceanography Command

OBJECTIVE: The Principal Investigators chair the Atmospheric COMNAVMETOCCOM Independent Model Review Panel (CIMREP). This panel is tasked to perform independent validation reviews of models submitted to the Oceanographic and Atmospheric Master Library (OAML), including future model improvements.

SUMMARY: Two Atmospheric CIMREPs were convened in the past two years. The major one concerned the Radio Physical Optics (RPO) model developed by NRaD which was accepted into OAML with rather minor revisions. An-

other CIMREP is presently active in evaluating two models; one for computing pressure altitude and density altitude (PADA) and one for a temperature utility (TEMP UTIL) computation. Work in 1996 focused on planning the Joint EM/EO Refractive Effects Symposium to be held in Monterey, June 1997.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Electromagnetic propagation

TROPICAL CYCLONE MOTION STUDIES

Patrick A. Harr, Research Assistant Professor
Russel L. Elsberry, Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVES: In the most general context, the large-scale circulation may affect tropical cyclone motion by defining a steering current in which the tropical cyclone moves. Prior research that has been sponsored by the Office of Naval Research has demonstrated that tropical cyclone motion deviates from a broadly defined steering current and the structure of the tropical cyclone may be an important factor in determining the deflection from the environmental steering. Furthermore, the large-scale steering influence on tropical cyclone motion may act over larger space scales and longer time scales than structure influences. However, the tropical cyclone structure characteristics that affect short-term motion may directly respond to the variability of the broader scale influences. Therefore, specific objectives of this research are aimed at improving tropical cyclone track forecasting over a broad range of space and time scales.

Observations and experience from two tropical cyclone motion field programs (TCM-92 and TCM-93) that were sponsored by the Office of Naval Research suggested that the outer wind structure of the mature tropical cyclone, which is important to understanding its motion over shorter time scales (i.e., 1 to 3 days), is dependent on the growth, evolution, and decay characteristics of mesoscale convective systems (MCSs) and associated midlevel vortices. Therefore, specific research objectives to improve tropical cyclone motion forecasts over short-ranges, which may be dependent on structure characteristics, are to identify the factors that control MCS evolution within the tropical cyclone environment and to define the relationships between MCS evolution and the large-scale environment.

SUMMARY: Results have been obtained with respect to the relationship between large-scale circulations, MCS evolution, tropical cyclone structure, and tropical cyclone motion. Two studies (Harr et al. 1996) defined different types of MCS and tropical cyclone structure evolution under very different large-scale conditions that existed during separate periods of TCM-93. During each case, the large-scale environment was conducive to repeated MCS formations with associated midlevel vortex development. In one instance (Harr et al. 1996), repeated MCS development eventually resulted in formation of a small tropical cyclone. During a second period (Harr et al. 1996), repeated MCS formations occurred in a large monsoon depression that was slowly moving westward along the monsoon trough that existed over the tropical western North Pacific. Repeated MCS formations and the interactions between the MCSs and the large-scale circulation eventually contributed to the organization of a large tropical cyclone. These two cases indicated that the wind structure characteristics of the mature tropical cyclone may be determined by the MCS evolution and intensification, which may be very dependent on the large-scale environment, as the tropical cyclone is forming.

It is expected that the synthesized results from the various components of this project will transition into a forecast guidance system that will alert tropical cyclone forecasters to the variability in extended-range tropical cyclone characteristics that will then provide the framework for categorization of MCS, tropical cyclone structure and motion characteristics.

PUBLICATIONS:

Harr, P.A., and Elsberry, R.L., "Structure of a Mesoscale Convective System Embedded in Typhoon Robyn during TCM-93," Monthly Weather Review, Vol. 124, No. 4, April 1996.

Harr, P.A., Kalafsky, M.S., and Elsberry, R.L., "Environmental Conditions Prior to Formation of a Midget Tropical Cyclone," Monthly Weather Review, Vol. 124, No. 8, August 1996.

Chang, C.-P, Chen, J.M., Harr, P.A., and Carr, L.E., "Northwestward-Propagating Wave Patterns over the Tropical Western North Pacific during Summer," Monthly Weather Review, Vol. 124, No. 11, pp. 2245-2266, November 1996.

Harr, P.A., Elsberry, R.L., and Chan, J.C.L, "Transformation of a Large Monsoon Depression to a Tropical Storm during TCM-93," Monthly Weather Review, Vol. 124, No. 12 December 1996.

CONFERENCE PRESENTATIONS:

Harr, P. A., "Multiscale Aspects of Tropical Cyclone Structure," Office of Naval Research Symposium on Tropical Cyclones, Melbourne, Australia, 9-13 December 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Tropical cyclone, tropical meteorology, mesoscale convective systems

IMPACTS OF THE EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES ON PREDICTIONS OF MIDLATITUDE CIRCULATION SYSTEMS

Patrick A. Harr, Research Assistant Professor
Russell L. Elsberry, Professor
Department of Meteorology
Sponsor: Naval Research Laboratory-Monterey

OBJECTIVE: The primary objectives of this project are to identify physical processes that are associated with the extratropical transition of tropical cyclones that may or may not be forecast accurately by the Navy Operational Global Atmospheric Prediction System (NOGAPS), and improved description of the resulting impacts on model forecast skill throughout the synoptic time scale.

SUMMARY: The variability in NOGAPS forecast skill associated with the extratropical transition of tropical cyclones over the western North Pacific was examined in relation to the variability in the midlatitude circulation pattern into which the cyclone is transitioning (Harr et al. 1996). The midlatitude circulation variability, which was defined by an empirical orthogonal function (EOF) analysis, provided a framework for identification of several synoptic models that could be applied at the time of transition to assess the potential impact of a transitioning cyclone on forecasts of downstream midlatitude circulations. Within this framework, the midlatitude circulation variability associated with seasonal changes was separated from variability associated with different circulation characteristics at transition times.

The variability in numerical forecast skill associated with extratropical transition was examined with respect to the framework of midlatitude circulation variability. It was found that the variability in NOGAPS forecast skill associated with extratropical transition was related to the conditions under which the cyclone in transitioning. Synoptic models based on the framework to the variability in midlatitude circulations at the time of extratropical transition helped to identify periods of reduced forecast skill that lead to greater utility of the numerical guidance.

PUBLICATION:

Harr, P.A., Elsberry, R.L., Klein, P.M., Hogan, T.F., and Clune, W.M., "Impacts of the Extratropical Transition of Tropical Cyclones on Midlatitude Circulation Systems," 15th Conference on Weather Analysis and Forecasting, American Meteorological Society, Norfolk, VA, 19-23 August 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Tropical cyclones, extratropical transition, midlatitude circulation variability

PROJECT SUMMARIES

GLOBAL AND TROPICAL SYSTEMS

Tom Murphree, Research Assistant Professor
C.-P. Chang, Professor
J.-M. Chen, Research Assistant Professor
Department of Meteorology
Sponsor: Naval Research Laboratory

OBJECTIVES: This continuing project is designed to: (1) identify the dominant mechanisms of short-term climate change in the global atmosphere-ocean system, (2) evaluate the atmospheric and oceanic products produced by operational analyses and forecasts, and (3) contribute to the improvement of atmospheric and oceanic extended range forecasts.

SUMMARY: In collaboration with colleagues at NRL-Monterey and NOAA-Pacific Fisherie Environmental Group, four main research topics were pursued during 1996:

1. Remote Impacts of Tropical Cyclones: Studies of the impacts of tropical cyclones (TCs) were continued on the extratropical circulation with additional modeling experiments and observational analyses. The modeling studies were done with both the Navy's operational global forecast model (NOGAPS) and a nonlinear global shallow water model with realistic ambient fields. The observational studies were of several periods during the 1995-1996 La Niña event. Both sets of studies provided confirmations of earlier results, especially in indicating the importance of interactions between the upper tropospheric outflow from the TCs and the nearby subtropical jet. This interaction initiates quasi-geostrophic wave activity which subsequently propagates and amplifies along the jet. The largest impacts of this process occur at the downstream end of the jet. TC activity in the maritime continent region during the La Niña event appears to have been a major factor in producing the large tropospheric circulation anomalies observed at the downstream end of the East Asian - North Pacific jet throughout the 1995-1996 winter.

2. Propagation of Extratropical Intraseasonal Waves: Comparisons of observed and modeled intraseasonal waves were continued, with an emphasis on 6-to-30 day waves propagating from the extratropics into the tropics during the northern winter. The observed fields were from eight years of ECMWF analyses. The model output was from a ten year integration of the NOGAPS model. Both the observed and modeled waves showed clear propagation from the northern hemisphere into the tropics in the regions of upper tropospheric westerlies (e.g., the eastern Pacific and Atlantic sectors). However, the model failed to simulate the continued propagation of these waves into the southern hemisphere in the eastern Pacific. This appears to be the result of a model biases in the East Asian - North Pacific jet and the upper tropospheric westerlies over the tropical Pacific. These biases have significant impacts on the model's extended range forecasts. The causes of these model biases are now being investigated.

3. Large-Scale Dynamics of Precipitation Extremes in Western North America: This is a new topic within this research project. The focus is on extreme precipitation events in western North America occurring on intraseasonal scales, and on the global scale dynamics that produce these events. Such events include the 1992-1993 winter flooding in the Southwest and the 1996-1997 winter flooding in the Pacific Northwest. The initial work has been to identify and characterize the major extremes since 1980. The results show that the extreme positive precipitation events were associated with northeastward winds throughout the troposphere. In the lower troposphere, these winds had a high precipitable water (PW) content and occurred over positive sea surface temperature anomalies (SSTAs) in the northeast Pacific. The extreme negative anomalies were associated with westward or southwestward winds, or wind anomalies, low PW, and negative SSTAs. The causes of the SSTAs are unclear, but the SSTAs are broadly consistent with the anomalous Ekman pumping expected from the surface wind anomalies. In several cases, the wind anomalies appear to have arisen from disturbances in southeast and eastern Asia (e.g., the positive phase of a Madden-Julian oscillation, a persistent cold surge in eastern China).

4. Decadal Scale Air-Sea Interactions in the North Pacific: The studies of the impacts of recent El Niño and La Niña events on the North Pacific have been expanded to consider the causes of decadal scale SST and atmospheric circulation shifts over the last several decades. The initial focus is on the major shift that occurred in the mid-1970s and the global scale ocean, atmosphere, and land anomalies associated with that shift. The preliminary results show that the North Pacific shifts in SST and surface winds were part of a larger anomaly pattern extending across much of Eurasia, the Indian ocean, and the South Pacific. Examinations are beginning on the dynamics of this pattern and the possible teleconnections—in particular, the role of interannual and decadal variations in the Asian-Australian monsoon system.

PUBLICATION:

Reynolds, C., Gelaro, R., and Murphree, T., "Observed and Simulated Northern Hemisphere Intraseasonal Circulation Anomalies and the Influence of Model Bias," Monthly Weather Review, Vol. 124, No. 6, p. 1100-1118, 1996.

CONFERENCE PRESENTATION:

Murphree, T., "The Large Scale Context for Recent Precipitation Extremes in Western North America," The 13th Annual Pacific Climate Workshop, National Oceanographic and Atmospheric Administration, Pacific Grove, CA, April 1996.

DoD KEY TECHNOLOGY AREAS: Other (Environmental Effects)

KEYWORDS: Climate dynamics, El Niño, La Niña, quasi-geostrophic waves, teleconnections, tropical cyclones, extended range forecasts

MAURY PROJECT

Tom Murphree, Research Assistant Professor
Department of Meteorology
Sponsor: U.S. Naval Academy

OBJECTIVES: The objective of this project is to develop and present educational materials on physical oceanography to pre-college teachers.

SUMMARY: This is a new project begun in 1996 and conducted in collaboration with colleagues at the U.S. Naval Academy (USNA) and the American Meteorological Society (AMS). The project is part of a larger national Maury Project administered by the AMS, and funded by the National Science Foundation; the Chief, Naval Meteorology and Oceanography Command (CNMOC); and NOAA. A mre complete description of the national Maury Project is contained in Smith et al.. (1996).

The purpose of the NPS part of the national project is to develop and present educational materials on physical oceanography to pre-college teachers participating in the national Maury Project. The oceanographic subjects covered by the NPS project include: currents, waves, tides, Ekman processes, air-sea interaction, ocean acoustics, El Niño and La Niña, satellite sensing of the ocean, at-sea research methods, computer-aided analysis of oceanographic data, and ocean modeling. A number of presentations were made to the Maury Project teachers during their summer course at USNA during July 1996. These included at-sea, laboratory, and classroom presentations. As part of the NPS project, six additional activity-and-lecture presentations were made to Monterey area students and to educators at the Monterey Bay Aquarium. In collaboration with colleagues at USNA and AMS, a number of journal articles, teacher guides, and classroom activities were developed and published to introduce key physical oceanography subjects to the Maury Project teachers and, through these teachers, to other teachers and to pre-college students.

PUBLICATIONS:

Murphree, T., and Brennin, R., "Voices From the Deep: Acoustic Tracking of Whales," Current: The Journal of Marine Education, Vol. 13, No. 4, p. 14-17.

Murphree, T., and Sullivan, D., "The Shape of the Sea Surface," Current: The Journal of Marine Education, Vol. 13, No. 4, p. 24-27.

Smith, D.R., Guth, P.L., Viera, M.R.C., Whitford, D.J., Jones, D.W., Miller, E.J., Eisman, G.R., Strong, A.E., Kren, R.S., Dillner, D.S., Geer, I.W., McManus, D.E., and Murphree, J.T., "The Maury Project: Providing Teachers With the Physical Foundations of Oceanography," Proceedings of the Fourth International Conference on School and Popular Meteorological and Oceanographic Education, Royal Meteorological Society, Bracknell, Berkshire, U.K., 1996.

The Maury Project Team, Measuring Sea Level From Space: A Maury Project Teacher's Guide, American Meteorological Society, Washington, DC, 16 pp, 1996.

The Maury Project Team, Upwelling and Downwelling: A Maury Project Teacher's Guide, American Meteorological Society, Washington, DC, 14 pp, 1996.

CONFERENCE PRESENTATIONS:

Smith, D.R., Guth, P.L., Viera, M.R.C., Whitford, D.J., Jones, D.W., Miller, E.J., Eisman, G.R., Strong, A.E., Kren, R.S., Dillner, D.S., Geer, I.W., McManus, D.E., and Murphree, J.T., "The Maury Project: Providing Teachers With the Physical Foundations of Oceanography," The Fourth International Conference on School and Popular Meteorological and Oceanographic Education, Royal Meteorological Society, Edinburgh, U.K., July 1996.

OTHER:

Murphree, T., Satellite Views of the Ocean and Atmosphere, a 14-minute video with a companion 7-page text presenting fundamental aspects of physical oceanography and air-sea interaction for use in pre-college teaching of Earth and physical sciences, Department of Meteorology, Naval Postgraduate School, Monterey, CA, July 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Physical oceanography, pre-college science education

MARINE ADVANCED TECHNOLOGY EDUCATION PROJECT

Tom Murphree, Research Assistant Professor
Department of Meteorology
Proposed Sponsor: National Science Foundation

OBJECTIVES: The objective of this project is to develop a national center for marine advanced technology education.

SUMMARY: This is a proposed project on which preliminary work has begun. This project is part of a larger proposed national project, the Marine Advanced Technology Education (MATE) Center, which will have its headquarters at Monterey Peninsula College (MPC) in Monterey, CA. The primary partners on the MATE Center project include: MPC, NPS, Monteey Peninsula Unified School District, Prince William Sound Community College, Harbor Branch Oceanographic Institution, and Oceaneering International, Inc. A proposal for funding for the MATE Center has been submitted by these and other partners to the National Science Foundation (NSF). This proposal has been favorably reviewed by NSF so far, and funding seems likely.

The MATE Center will coordinate and facilitate the development of a national program for marine science, engineering, and technology education involving high schools, technical schools, community and four-year colleges, and graduate schools. The Center will emphasize intensive interaction between educational institutions and industry, military, government, and labor organizations. The Center will focus on the areas of marine technology in which the future needs of the nation and employers are unlikely to be met by the existing educational system.

The main NPS roles in the MATE Center will be: (1) development and coordination of collaborations between four-year colleges, graduate schools, and research organizations, (2) development and coordination of collaborations with the U.S. Navy and Coast Guard, (3) development of curricula, especially in the physical aspects of oceanography, and (4) assistance in the development and coordination of the Center's distance learning programs.

The preliminary work conducted in 1996 by NPS and its partners focused on developing and conducting a national invitational forum on marine advanced technology, marine technicians, and the marine technology educational system. The forum was held in November 1996 in Monterey. Funding came from an NSF planning grant, with additional support from Scripps Institution of Oceanography, Moss Landing Marine Laboratories, and Deep Ocean Exploration

and Research, Inc. NPS was extensively involved in designing the forum, and in conducting initial analyses of the main branches of marine technology and the roles of various organizations in marine technology education. During the forum, the organizers and participants analyzed the current state, and likely future state, of marine technology and marine technology education. They also identified the major national needs in marine technology education and developed a set of recommendations for addressing those needs. The main recommendation was for a national center which has now been designed and proposed to NSF as the MATE Center.

CONFERENCE PRESENTATION:

Murphree, T., "The Roles of Industry, Government, Military, Research, Labor, and Educational Organizations in Marine Technology Education," The Marine Advanced Technology Education Forum, National Science Foundation, Monterey, CA, November 1996.

OTHER:

Crane, N., Matray, K., Murphree, T., Robertson, V., Stewart, B., Sullivan, D., and Carless, J. Marine Advanced Technology Education: A Report From a National Forum Funded by the National Science Foundation, Monterey Peninsula College, Monterey, CA, in press.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Marine technology, science and engineering education

MESOSCALE COASTALLY-TRAPPED RESPONSE TO SYNOPTIC-SCALE VARIABILITY

Wendell A. Nuss, Associate Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: The primary long term goal of this ongoing project is to understand the role that synoptic-scale circulations play in the generation, propagation and decay of coastally-trapped disturbances. Additional goals are to understand the interaction of large-scale flows with coastal topography and the nature of the mesoscale response on the lee and windward sides of the topography, as well as to improve our forecasting of the mesoscale structure based uon the large-scale circulation.

SUMMARY: A variety of significant tasks have been completed during the past year of this multi-year effort. Most significant was the planning, execution, and completion of a field program during the period from 1 June to 30 September 1996. A large amount of data was collected and is being processed for analysis and distribution to other investigators, including observations from several flights by the Naval Postgraduate School airplane. In addition, a study of the 1994 and 1995 coastally-trapped disturbances was completed to define the synoptic-scale structure and coastal evolution for these events.

Time series analysis of the onset of coastal southerly winds at the coastal buoy sites was used to characterize the life cycle of 8 coastally-trapped disturbances. This analysis showed that coastally-trapped disturbances can be characterized by propagating and non-propagating events, where the shift in the winds from northerly to southerly is observed to progress up the coast (propagating) or occur simultaneously at all locations (non-propagating). Some events even show southward propagation. The National Center for Environmental Prediction (NCEP) ETA model analyses and forecasts were then used to examine what distinguishing synoptic-scale structures occurred in propagating and non-propagating coastal southerly winds. Results show that both type of events show general synoptic-scale structures and evolutions that were similar to the synoptic composites produced by Mass and Bond (1996).

However, a more detailed examination revealed that propagating disturbances were strongly associated with offshore flow at 850 mb along the entire California coast while non-propagating disturbances had onshore flow at 850 mb along the southern California coast. In addition to these scientific tasks, the Principal Investigator for this program

completed and distributed the Science Plan for the field study, coordinated the field activities, and lead several informal workshop during and just after the field program.

PUBLICATION:

Ralph, F.M., Armi, L., Bane, J.M., Dorman, C., Neff, W.D., Neiman, P.J., Nuss, W.A., and Persson, P.O.G., "Observations and Analysis of 10-11 June 1994 Coastally Trapped Disturbance," submitted to Monthly Weather Review, 1996.

CONFERENCE PRESENTATION:

Nuss, W.A., "Forecasting the Initiation of West Coast Coastally Trapped Disturbances," First Conference on Coastal Atmospheric and Ocean Prediction, Atlanta, GA, January 1996

TECHNICAL REPORT:

Nuss, W.A., "Coastal Meteorology Science Plan," Naval Postgraduate School Technical Report, March 1996.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Coastal meteorology, coastal forecasting, coastal observations

REAL-TIME ENVIRONMENTAL INFORMATION NETWORK AND ANALYSIS SYSTEM (REINAS)

Wendell A. Nuss, Associate Professor
Paul A. Hirschberg, Research Associate Professor
Department of Meteorology
Sponsor: University of California, Santa Cruz

OBJECTIVE: The objective of this research is to develop a mesoscale observing network and real-time data assimilation system for the Monterey Bay region and assist University of California, Santa Cruz, develop computer data base and visualization tools.

SUMMARY: This is an ongoing project and during 1996 the Naval Postgraduate School contribution to this joint research effort has focused o the development of the data assimilation system and to test the REINAS data base system from a user perspective. The data assimilation system was adapted to use the NCAR/Penn State University mesoscale model (MM5) instead of the Navy Operational Regional Atmospheric Prediction System (NORAPS) nested model.

This move to MM5 upgraded the model component in the data assimilation system from a hydrostatic to non-hydrostatic model, which is more appropriate for the small scale circulations under investigation. Plans are underway to utilize the Navy's non-hydrostatic model (COAMPS) in the future when computing resources become available. The multiquadric data assimilation has been running operationally to produce hourly surface wind analyses for the Monterey Bay region since July 1996. The three dimensional assimilation is about to become operational to provide complete real-time mesoscale forecast for the Monterey Bay region. New data streams have been added to REINAS during 1996 through the combined efforts of NPS and UCSC. GOES-9 satellite images, routine surface observations, and additional wind profiler data are now part of the REINAS data base. In addition to these technological contributions, the REINAS system has been used to conduct a scientific study of the Monterey Bay sea breeze during the summer of 1996. Preliminary results show characteristic wind flow patterns that are associated with specific synoptic-scale background circulations. These results show considerable promise in understanding the sea breeze in a complex coastal environment.

CONFERENCE PRESENTATIONS:

Nuss, W.A., Mantey, P.A., Pang A., and Long, D.D.E., "The Real-time Information and Analysis System (REINAS)," 12th Conference on Interactive and Image Processing Systems for Meteorology, Oceanography and Hydrology, Atlanta, GA, January 1996

Hirschberg, P.A., Nuss, W.A., and Sirayanone, S., "Sensitivity of a Coastally Trapped Disturbance to Model Initial Conditions," First Conference on Coastal Atmospheric and Ocean Prediction, Atlanta, GA, January 1996

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Coastal meteorology, data management, coastal observing network

CASE STUDIES OF THE ABILITY OF THE NAVY'S MESOSCALE DATA ASSIMILATION SYSTEM TO DEPICT MESOSCALE PHENOMENA

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Sponsor: Naval Research Laboratory-Monterey

OBJECTIVE: The goal of this research is to examine the performance of the Navy's mesoscale data assimilation system for cases with strong mesoscale forcing. Features such as jet streaks and upper fronts stretch the limits of the capability of the data assimilation system but are important weather producers and therefore should be both analyzed and predicted.

SUMMARY: The work performed during calendr year 1996 involved preparing publications and writing computer code. The primary publication associated with this research described earlier work on an observational study of the meteorological conditions associated with the November 1991 San Joaquin Valley dust storm, an event which led to a 164-vehicle collision on Interstate-5.

Work was also begun on a comparison of five upper front cases over California. This research involved refining a computer program to evaluate and graphically portray a number of diagnostic quantities including frontogenesis, kinetic energy budget quantities, vertical circulation, and the topographic component of the vertical motion. Code was also developed to depict a feature's evolution through time. This was done by manually selecting the feature on a sequence of charts; the sequence is then plotted on a single chart. A conference paper detailed preliminary results from this work.

A third phase of this research involved developing computer code to read, decode, and perform quality control checks on aircraft observations. Automated aircraft observations have adequate resolution and accuracy to correctly depict the thermal gradients and wind shears associated with upper fronts. These data were then compared to analyses from the Navy's mesoscale data assimilation system in order to gauge how well it portrayed these features.

PUBLICATION:

Pauley, P.M., Baker, N.L., and Barker, E.H., "An Observational Study of the 'Interstate-5' Dust Storm Case," Bulletin of the American Meteorological Society, 1996, 693-720.

CONFERENCE PAPER:

Pauley, P.M., and Barker, E.H., "Upper-level Frontogenesis Over California As Depicted by the Navy's Mesoscale Data Assimilation System," 15th Conference on Weather Analysis and Forecasting, 19-23 ,August 1996, Norfolk, VA, 596-599.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Data assimilation, jet streak, upper front, aircraft observations

ANALYSES OF AIRCRAFT MEASUREMENTS OF BOUNDARY LAYERS AND STRATUS CLOUDS IN THE ARCTIC

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Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The objective of this project is to understand the boundary layer and cloud microphysics structure and evaluate aircraft measurement capability in the harsh Arctic environment. The goal is to construct optimal strategies for improved measurements in FIRE-III/SHEBA.

SUMMARY: Aircraft measurements on boundary layer turbulence structure were made by the NCAR C-130 during the Beaufort Arctic Storms Experiment (BASE) in 194. This data set has been analyzed to study the characteristics of the Arctic stable boundary layer and the cloud and boundary layer structure of the boundary layer capped by mixed-phase stratocumulus cloud. The stable boundary layer is characterized by weak turbulent mixing and significant wave and mesoscale perturbations. The mesoscale perturbations and wave motions are enhanced by the presence of open leads where convective plumes may be generated as a result of large air-water temperature difference. However, the aircraft measurements at the lowest level (40 m) failed to show traces of warm moist plumes from the open leads, mainly due to the strong thermal stratification in the lower boundary layer. Further analysis on the transient turbulence phenomenon in the stable boundary layer has been planned in the coming year using a new analysis technique.

Vertical profiles and mean characteristics of the boundary layer topped by a layer of mixed-phase cloud have also been studied. A case study indicated that the boundary layer was decoupled from the surface, a situation similar to subtropical stratocumulus-topped boundary layers. However, the reason for decoupling is not yet clear. Although the cloud water contents appear to be low in the mixed phase cloud case, strong radiative cooling was found at the top of the cloud, which is a main source in generating turbulence mixing in the upper boundary layer. The longwave radiative cooling appeared to be twice as large as that found in the water-phase stratocumulus topped boundary layer studied previously. Future study will focus on the characteristics of the turbulent eddies and the vertical variations of the eddy characteristics. Such a study will help reveal the role of various physical processes in the cloudy boundary layer. The radiative characteristics of the mixed phase cloud will also be analyzed in further detail.

PUBLICATION:

Paluch, I.R., Lenschow, D.H., and Wang, Q., "The Arctic Boundary Layer in the Fall Season Over Open and Frozen Sea," accepted by Journal of Geophysical Research, 1996.

CONFERENCE PRESENTATIONS:

Wang, Q., "Stable Boundary Layer and Turbulence Mixing in the Arctic," FIRE-III Science Team Meeting, Williamsburg, VA, 12-16, February 1996

Wang, Q., "Aircraft Observations of Turbulent Fluxes during BASE," SHEBA Phase I Meeting and Workshop, Seattle, WA, 17-18 September 1996.

Wang, Q., "Mean Structure in a Mixed-phase Stratocumulus-topped Boundary Layer," The FIRE-III Science Team meeting, Boulder, CO, 17-18, October 1996

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary layer meteorology, turbulence structure, stratocumulus clouds

CHARACTERISTICS OF THE MARINE BOUNDARY LAYER DURING ACE-1

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Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this project is to study mechanisms for turbulent mixing in the marine boundary layer. The goal is to examine the effects of boundary layer dynamics in determining the chemical and physical properties of atmospheric aerosols.

SUMMARY: This project focuses on the boundary layer dynamics that have profound effects on aerosol mixing and evolution in the marine boundary layers. The measurements were made During the Southern Hemisphere Aerosol Charactrization Experiment (ACE-1). The particular dataset used here was from the Lagrangian measurements where an instrumented aircraft followed the same air column for three days. The evolution of the boundary layer turbulence characteristics and entrainment mixing across the interface between the marine boundary layer and the troposphere have been studied. It is found that the boundary layer is separated into two layers. The lower layer is characterized by shear generated turbulence, while the upper layer is slightly stably stratified with very weak turbulence fields. Layering of aerosols is evident in the upper boundary layer. The boundary layer was also complicated by the development of patches of cloud in the upper boundary layer and a strong horizontal variation of sea surface temperature.

Entrainment velocity has been estimated using the flux method. This variable quantifies the extent of mixing between the upper and the lower boundary layer and is an important quantity in the budget equation for aerosol evolution.

CONFERENCE PRESENTATIONS:

Wang, Q., "Mean and Turbulence Structure of the Shear Marine Boundary Layers Observed during ACE-1," ACE-1 Data Workshop, Seattle, WA, 24-27 June 1996.

Wang, Q., "Evolution of the Marine Boundary Layer During Lagrangian Measurements of ACE-1," 1996 Fall meeting of the American Geophysical Union, San Francisco, CA, 15-18, December 1996.

Wang, Q., "Characteristics of the Marine Boundary Layer during Lagrangian B of ACE-1," ACE-1 Principal Investigator meeting, San Francisco, CA, 14 December 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary layer measurements, entrainment, aerosol study

TURBULENCE MIXING AND AEROSOL CHARACTERISTICS IN THE ARABIAN GULF

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Department of Meteorology
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this project is to study the variation of boundary and inversion structure in the coastal Arabian Gulf and the role of turbulent mixing in the formation of various aerosol size distribution.

SUMMARY: This is a joint project in collaboration with Dr. Andy Goroch at the Naval Research Lab at Monterey, CA. Measurements made by the UK MRF C-130 during the Navy ship ASW Readiness and Effectiveness Measuring (SHAREM) exercises are used for te analysis. The development of the marine boundary layer has been studied using two SHAREM 110 flights, one before the Shamal, and the other during the Shamal. Vertical cross-sections of the mean temperature, total water, and horizontal wind components have been studied. Large horizontal and vertical variations of the boundary layer depth and inversion structure were identified during the pre-Shamal period, where the continental airmass was transported over the relatively cool water. However, the development of the internal boundary layer is significantly different from the classical view of the development of a stable internal boundary layer in the coastal

region during offshore flow period. This difference is mainly caused by the vertical wind shear where forced convection prevails and maintains a well-defined marine layer. Further study will emphasize the entrainment process at the top of the marine layer and the temporal and spacial variation of the temperature and moisture structure at the interface. Case study from the SHAREM-115 flights will be used to explain the observed aerosol size distribution.

CONFERENCE PRESENTATION:

Goroch, A., Wang, Q., and Rogers, D., "Variations of the Marine Boundary Layer and Aerosol Properties in the Arabian Gulf," Abstracts of the 1996 Fall Meeting of the American Geophysical Union, San Francisco, CA, 15-18 December 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Boundary layer measurements, entrainment, aerosol study

COAMPS CLOUD PRODUCT RESEARCH

C.H. Wash, Professor
Department of Meteorology
Sponsor: Naval Research Laboratory-Monterey

OBJECTIVE: A variety of cloud forecast products will be developed from the new NRL mesoscale model, COAMPS. These will include estimates of cloud type and coverage, point cloud forecasts and forecast of important aviation forecast parameters.

SUMMARY: During the initial effort work focused on: 1) transferring complete COAMPS output from NRL to NPS, 2) reviewing COAMPS cloud and other outputs, 3) exploring visualization computation tools to work on the output. Complete model data sets are so large thatefficient approaches are needed to process the data and fast workstations are needed to prepare visualization displays, and 4) devising a COAMPS processing plan.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Cloud forecasting, COAMPS, aviation forecasting

SHAREM 110 REFRACTIVE FEATURES

C.H. Wash, Professor
K.L. Davidson, Professor
Department of Meteorology
Sponsor: Naval Research Laboratory

OBJECTIVES: Determine mesoscale processes responsible for refractive conditions during SHAREM 110 from merged in situ measurements, NORAPS fields, multi-spectral satellite analyses, and British Met Office Meteorological Research Flight (MRF) C-130 data.

SUMMARY: NPS Department of Meteorology faculty, staff and students, in collaboration with NRL scientists, performed analyses/interpretations of SHAREM 110 in situ data, NORAPS analyzed/predicted fields, and AVHRR multispectr satellite sensed data. These efforts were directed toward characterization of refractive conditions during SHAREM 110 special events or transition times. The relationship of sub-synoptic circulations as well as synoptic events to significant occurrences and changes in refractive conditions became clear.

THESIS DIRECTED:

Teadt, Troy, "Studies in Multispectral Determination of Boundary Layer Depth," Master's Thesis, Naval Postgraduate School, June 1996

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: SHAREM 110, marine atmosphere boundary layer, radar refraction, RPO, atmospheric measureme

FRONTAL MODELING

R.T. Williams, Professor
M.S. Peng, Research Associate Professor
Department of Meteorology
Sponsor: National Science Foundation

OBJECTIVE: The goal of this research is to improve the modeling of atmospheric fronts. This is a continuing project.

SUMMARY: The frontogenesis was studied over the ocean with the three-dimensional NRL regional model. The sea surface temperature which was in balance with the atmosphere initially, was independent of time. The experiments were carried out with K-theory and second order closure boundary layer parameterizations. The dynamics of the cold front which was moving overwarmer water were investigated in detail. It was found that the strong vertical mixing of momentum in the cold air caused the front to be more vertical and more intense at upper levels. Also studied was the influence of topography on fronts with a three-dimensional model with no heating or friction. Cold and warm fronts formed when a cyclone grew in an unstable baroclinic current. The mountains were circular or ellipsoidal and various scales and orientations were considered. As the cold fronts moved up the mountain slope they weakened and strong frontogenesis occurred as the front moved down the lee slope. When boundary layer effects were included, it was found that the mixing reduced the frontal strength variation as it crossed the mountain. Also studied was unbalanced frontogenesis and it was found that a discontinuity can form rapidly depending on the initial Rossby and Froude numbers.

PUBLICATION:

Li, S.-W., Peng, M.S., and Williams, R.T., "A Three-dimensional Study of the Influences of Mountains on a Front," Journal of the Atmospheric Sciences, Vol. 53, pp. 2757-2772, 1996.

Thompson, W.T., and Williams, R.T., "Numerical Simulations of Maritime Frontogenesis," accepted for publication in the Journal of the Atmospheric Sciences.

THESES DIRECTED:

Powell, J.H., "Boundary Layer Effects on Frontal Interaction with Topography," Master's Thesis, Naval Postgraduate School, June 1996.

Neves, A.P.C., "Unbalanced Frontogenesis with Constant Potential Vorticity," Master's Thesis, Naval Postgraduate School, December 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Fronts, boundary layer, topography

MECHANISMS OF TROPICAL CYCLONE STRUCTURE CHANGE

R.T. Williams, Professor
M.S. Peng, Research Associate Professor
Department of Meteorology
Sponsor: Office of Naval Research

OBJECTIVE: To determine the mechanisms which cause changes in tropical cyclone structure. This is a continuing project.

SUMMARY: The effect of the planetary vorticity gradient and the inclusion of a uniform mean flow on the intensification of tropical cyclones was studied using a primitive equation model. The most intense vortex developed on a constant *f* plane with zero mean flow. The structure of this storm was symmetric with respect to th vortex center. The presence of the beta effect or a large mean flow induced an asymmetric flow across the center of the vortex which inhibited the cyclone's intensification. Fourier analyses of the asymmetry showed that a deepening cyclone was associated with a weaker flow in the low-level wavenumber-one asymmetric wind field. This type of wind field allowed a more symmetric distribution of surface momentum and latent heat fluxes, as well as low-level moisture convergence. On the other hand, a weakening or non-intensifying cyclone was associated with a stronger flow in its wavenumber-one field. This type of flow generated asymmetric moisture convergence and momentum flux so that a phase shift developed between them. Cyclones located at the lower latitude (12N) deepened more rapidly than those at the higher latitude (22N) during the early stage. The most important result is the strong effects on cyclone evolution can occur in the lower troposphere in relation to the partition of heating between the symmetric and asymmetric parts.

CONFERENCE PAPER:

Peng, M. S., Jeng, B.-F., and Williams, R. T., "A Numerical Study on Development of the Tropical Cyclone: Beta Effect and Mean Flow Effect," Proceedings, Conference on Weather Analysis and Forecasting and Marine Meteorology, 4-6 March 1996, Taipei, Taiwan, ROC, 39-54.

CONFERENCE PRESENTATION:

Jeng, B.-F., Peng, M. S., and Williams, R. T., "A Numerical Study on Development of the Tropical Cyclone: Beta Effect and Mean Flow Effect," Conference on Weather Analysis and Forecasting and Marine Meteorology, Taipei, Taiwan, ROC, 4-6 March, 1996.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Tropical cyclone, vortex, beta-effect, intensity

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SYNOPTIC AND MESOSCALE INFLUENCES ON REFRACTION DURING SHAREM 110

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Highly variable refractive conditions over the Persian Gulf and Gulf of Oman are studied during the SHAREM 110. Data collected during SHAREM 110, conducted in February 1995, included the Naval Operational Regional Atmospheric Prediction System (NORAPS), a large data base of upper air profiles, shipboard surface weather observations, and satellite imagery. Four different meteorological regimes occurred; pre-Shamal or Kaus, Shamal, Northeast Monsoon, and a short Shamal event. In addition to discussing the effects of synoptic meteorology on refraction during these periods, topography is also found to be a major factor in influencing refractive variability. The land/sea breeze was also found to be very important in modifying the low level refractive structure, especially in the Gulf of Oman.

EXAMINATION OF SPY-1B PERFORMANCE PREDICTED BY RPO/EREPS FOR SHAREM 110 ENVIRONMENTS

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The littoral atmosphere and the cruise missile are of major concern for today's warships. The time distance problem for a successful detect-to-engage sequence is compounded with faster lower flying missiles. The need for tools to optimize the radar performance on board U.S. Navy ships is identified. The SPY-1B radar is discussed to identify operator inputs for the Navy's propagation loss models Radio Physical Optics (RPO) and Engineers Refractivity Effects Prediction System (EREPS). Based on vertical atmospheric radiosondes from SHAREM 110 an examination of RPO and EREPS show that the models have the fidelity to account for tactical parameters. Prediction of signal to noise versus range are compared to SHAREM 110 SPY-1B radar track data with mixed results. The mixed results are attributed to the unrepresentativeness of the environmental profiles and uncertainties in the radar data. Recommendations for future exercises include realistic threats and improved data gathering including the analysis of the SPY-1B data tapes.

A SYNOPTIC PREDICTION OF EXTREME SUBREFRACTION

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Microwave communications and data links are a proven terrestrial technology around the globe. Their introduction to United States naval assets as part of the Cooperative Engagement Capability places them in an unfamiliar setting. The atmosphere over water imposes certain limitations upon electromagnetic transmissions that should be appreciated and understood by those employing these systems at sea. This thesis is a case study of the "Blizzard of '96" snowstorm that hit the Mid-Atlantic United States on January 7, 1996, and its effects upon the Wallops Island, Virginia Microwave Test Range operated by The Johns Hopkins Applied Physics Laboratory. An analysis of microwave events (specifically sustained deep fades) on the basis of predictable synoptic weather systems is presented along with conclusions and recommendations for the operators of microwave communications systems by naval units.

COMINT ANALYSIS IN A LITTORAL ENVIRONMENT

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This study consists of a performance evaluation of ship-mounted COMINT systems collecting against VHF/UHF data/voice signals in a littoral environment. The detection range for each combination of collector and emitter was determined with the aid of the AFIWC software program "Passive Detection (PD)". The atmosphere propagation effects and phenomena such as trapping and ducting were taken into account using the NCCOSC software program "Engineer's Refractive Effects Prediction System (EREPS)". The performance of COMINT systems against representative RF receiver and transmitter systems, including cellular and SATCOM systems in the UHF band, was evaluated and summarized in a matrix, as the end product of this work. The unclassified study was limited to the capability of the modeling programs, including the availability of the environmental data concerning the area as well as the characteristics of the equipment evaluated. Geolocation was not included.

CALIFORNIA SEA BREEZE STRUCTURE AND ITS RELATION TO THE SYNOPTIC SCALE

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The sea breeze structure was examined at several locations along the California coast during the summers of 1993-1995. The sea breeze was objectively classified as three distinct types: gradual, frontal and rapid onset. The sea breeze wind and virtual temperature structure were determined at the surface and throughout the planetary boundary layer. Distinct local and regional-scale sea breeze circulations were identified for each sea breeze classification. To examine the role of the synoptic-scale wind patterns on the development of sea breeze type/structure, an objective classification scheme was developed and applied along the West Coast of California. The synoptic-scale classification scheme associated large-scale wind regimes with variability in the position of the eastern North Pacific Ocean anticyclone. Using the classification scheme, the "continental" sea and land breezes, previously only seen in long term statistical analysis, emerged as important large-scale circulation modes. The role of the synoptic-scale wind circulation patterns in determining the sea breeze types was explored. The variability in coastline geometry and inland heating sources was determined to be essential in the development and understanding of the sea breeze circulation types.

AN INTERPRETATION OF EXTRATROPICAL CYCLOGENESIS USING ADJOINT METHODS

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Adjoint methods are used to examine the development of idealized and real extratropical cyclones. This research represents the first use of adjoint sensitivity that includes moist physical processes to study complete cyclone life cycles. Adjoint sensitivity is a computationally efficient technique for determining, in a comprehensive sense, the sensitivity of a forecast aspect (J) to small perturbations of model variables at earlier times in a numerical forecast, including initial conditions. In these simulations, J is selected to represent central pressure or vorticity of forecast cyclones. Specification of lower tropospheric (500-800 hPa) temperature and moisture near the incipient cyclone at the beginning of the storm track appears especially critical to cyclone prediction. Rapid cyclone intensification appears

related to enhancement of dry baroclinic instability by latent heat release from nonconvective precipitation near the cyclone warm front. Cyclones can also be intensified by reduced surface stress and higher sea-surface temperature in the warm sector of the storm. The cyclone life cycle may be viewed in terms of an initially small-scale instability that propagates upward from a baroclinic zone in the lower troposphere, and leads to intensification of anomalies in both the upper and lower troposphere at the end of the storm track.

SYNOPTIC APPLICATIONS OF NOAA MICROWAVE SOUNDING DATA

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A statistical study of satellite-derived channel 3 Microwave Sounding Unit (MSU) brightness-temperatures and conventionally derived fields by Parke (1994) showed that the MSU can be used to locate baroclinic waves. Most significantly, Parke found high negative average correlations between the synoptic-scale MSU and mid-level height patterns in accordance with theory. However, there were instances in his six-month sample where the correlations were not as expected. In this thesis, three reasons for these unexpected correlations are investigated. One reason is the inclusion of erroneous data. Another is the statistical method. In particular, the Errico (1985) method of scale separation is found to not remove all unwanted wavelength signals in the data. Moreover, the Eulerian-based statistics produce misleading results at times. Results from an example implementation of a simple semi-Lagrangian approach suggests that such a method might produce more reasonable correlations. Thirdly, synoptic regime appears to be a factor. Classifying synoptic regimes with a thermal wind zonal index shows some utility in identifying patterns that are associated with expected correlations. Finally, two case studies are presented that demonstrate the usefulness of MSU data in conjunction with conventional data in individual forecasting situations.

BOUNDARY LAYER EFFECTS ON FRONTAL INTERACTION WITH TOPOGRAPHY

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A hydrostatic, primitive equation model with frontogenetical deformation forcing is used to simulate the passage of cold fronts over a two-dimensional ridge. The model includes a K-theory planetary boundary layer (PBL) parameterization with implicitly defined diffusion coefficients. Numerical simulations are performed for synoptic-scale ridges of varying widths both with and without frontal forcing. These results are compared to simulations that do not include a PBL parameterization, similar to previous inviscid studies by Williams et al.

Relative to the inviscid results, the PBL simulations produced reduced frontolysis on the upwind slope and reduced frontogenesis on the lee slope, resulting in significantly smaller frontogenetic variations over the mountain. This is caused by convergence forcing in the well-mixed layer offsetting the overall frontolytical forcing on the upwind slope, and greatly reduced lee side convergence forcing due to the PBL. In contrast to the inviscid results, the final downstream front is weaker in the mountain simulations than in the flat-topography control case when PBL effects are included. In all PBL simulations, gravity wave generation is greatly reduced and no lee side hydraulic jumps are observed. In general, the inclusion of a PBL into the model results in more realistic wind and temperature fields compared to the inviscid model simulations.

THE EFFECT OF 300 MB DIVERGENCE ON SURFACE CYCLOGENESIS

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Quantitative predictions of surface extratropical cyclone development are correlated to the degree of upper-level forcing from 500 mb vorticity advection and 300 mb divergence. Although it is difficult to obtain an accurate analysis of upper-level divergence, modern models and data assimilation procedures do produce consistent divergence fields. The divergence field partitioned into the longitudinal (alongstream) and transverse (cross-stream) components approximately estimates the effect of curvature and jet streaks on cyclone intensification. Verification of the Eta model indicated no significant difference in the mean central pressure to a confidence level of 95%, and verification of the 300 mb divergence was very similar to the 500 mb vorticity advection. The presence of subgeostrophic flow in the trough and supergeostrophic flow in the ridge was noted with the longitudinal divergence. Large variability in longitudinal divergence reflected some sensitivity to small-scale perturbations in the height field. Transverse divergence fields showed greater consistency and projected a similar wind pattern to the classic jet streak model, however, modifications were seen as ageostrophic winds may also be directed toward regions of height falls. The composition of the total divergence from the longitudinal and transverse divergence is about 50:50. However, with very large total divergence values, the dominant contributor is the transverse divergence.

SEASONAL VARIATION OF DIURNAL DEEP CONVECTION OVER THE SOUTH CHINA SEA AND SURROUNDING REGIONS

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Diabatic heating in the tropical regions is a major energy source by which atmospheric circulation is driven. This energy mainly consists of the latent heat released by deep convective clouds in the tropics.

Large diurnal variations of convective activities exist over continents, large islands and their adjacent ocean regions such as the Indochina Peninsula, Tibetan Plateau, North Australia and the maritime continent regions. Additionally, the diurnal phase and amplitude of deep convection undergoes large regional and seasonal variations. In general the maximum components of the diurnal cycle occurs in the same area as the maximum convection. Through statistical and composite methods, the seasonal and regional variations of the ten-year mean diurnal cycle of convection is examined in terms of phase and amplitude fluctuations over the continents, large islands, coastal and open ocean areas of the South China Sea and surrounding regions.

WIND PROFILER STUDY OF THE CENTRAL CALIFORNIA SEA/LAND BREEZE

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Sea/land-breeze events on the Monterey Bay are examined using data from the 915-MHz wind profiler and RASS systems. These sensors were deployed during Jun-Aug 1994 in conjunction with the REINAS Project conducted by various scientific institutions in the region. Data analyzed are continuous radar and virtual temperature returns located at four sites strategically positioned around the bay. This relatively new remote sensing device provides information on

maximum/minimum sea/land-breeze heights, onset and cessation times, virtual temperature distribution with height, and the effect of mountainous coastal topography on the sea and land breeze system.

STUDIES IN SATELLITE MULTI-SPECTRAL DETERMINATION OF BOUNDARY LAYER DEPTH

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Satellite derived images of boundary layer properties are generated from AVHRR data collected during SHAREM 110 (6 February - 18 February 1995) and during a Naval Postgraduate School cruise (16 May 1995) for comparison with in-situ data. The technique, proposed by Kren (1987), verified by Smolinski (1988) and applied by Walsh (1994) uses NOAA AVHRR channels 1, 2, 4 and 5 and the relationships between radiative extinction and relative humidity and atmospheric absorption and column water vapor. The percent of total atmospheric water vapor contained in the MABL is determined, via the method of Walsh (1994), and is provided to the algorithm. The technique successfully mapped boundary layer heights for two different coastal regimes, Persian Gulf and Monterey Bay region. The method failed in the Gulf of Oman region for a case strongly affected by continental influences containing a large concentration of land aerosols. The results also show that the algorithm is closely tied to the sea surface temperature and can only retrieve the layer depth most closely associated with the surface. Therefore, this technique cannot indicate the presence of elevated layers not associated with the surface.

ANALYSIS OF SHIPTRACK PERSISTENCE WITH IN SITU CLOUD MEASUREMENTS AND SATELLITE RETRIEVED REFLECTANCE

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Shiptracks detected on Advanced Very High Resolution Radiometer (AVHRR) satellite images possess longer detection lives and down-track brightness than expected. A simple model of physical processes is developed to correlate the ship injected aerosols to the subsequent affects on cloud condensation nuclei, droplet distribution, effective radius, and albedo. The theoretical dispersion model is tested using measured values corresponding to the terms of the model equation. The data sets consisted of in situ aircraft droplet concentration and effective radius cross-shiptrack profiles and AVHRR satellite reflectance values collected during the Monterey Area ShipTracks (MAST) experiment. Strong reinforcement of the model's droplet concentration, effective radius, and reflectance relationships is shown. The near constant value in the observed downtrack fractional change of droplet concentration disputes the decreasing fractional changes of droplets predicted by dispersion associated with track widening. The results indicate down-track modification of cloud and droplet concentrations able to maintain track brightness and track detection life.

EVALUATION OF NORTHWEST PACIFIC TROPICAL CYCLONE TRACK FORECAST DIFFICULTY AND SKILL AS A FUNCTION OF ENVIRONMENTAL STRUCTURE

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A Systematic Approach for tropical cyclone track forecasting by Carr and Elsberry defines the Synoptic Environment of each cyclone in terms of ten Synoptic Pattern/Region combinations. Because storms in each Pattern/Region combination have characteristic tracks that are dramatically different, it is hypothesized that the degree of difficulty in forecasting the tropical cyclone track, and the skill of the Joint Typhoon Warning Center (JTWC) track forecasts will be a function of the Synoptic Environment. The degree of forecast difficulty is defined by comparing forecast track errors (FTEs) of the operational CLImatology and PERsistence (CLIPER) technique in each of the ten Pattern/Region combinations with the overall CLIPER FTEs. The most difficult combinations are the recurving scenarios of Weakened Ridge Region of the Standard Pattern and the Southerly Flow Region of the Multiple tropical cyclone Pattern. The least difficult combinations are the Dominant Ridge Regions of the Standard and Gyre Patterns. The JTWC forecasts have statistically significant skill compared to the no-skill CLIPER forecasts for storms in the Standard/Dominant Ridge and North-Oriented Pattern/North-Oriented Region, which comprise nearly 77% of the five-year sample of JTWC forecasts. As transitions occur between the Synoptic Pattern/Region combinations, the degree of forecast difficulty increases, and the JTWC forecast skill decreases. Although the JTWC track forecasts are generally slow and slightly to the left, significant differences are found in many of the Pattern/Region combinations.

SYSTEMATIC AND INTEGRATED APPROACH TO TROPICAL CYCLONE TRACK FORECASTING IN THE EASTERN AND CENTRAL NORTH PACIFIC

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This study is the application of the meteorological framework in the Systematic Approach to tropical cyclone track forecasting of Carr and Elsberry to the eastern and central North Pacific tropical cyclones. All eastern and central North Pacific tropical cyclones from 1990-1993 are examined using 500 mb Navy Operational Global Atmospheric Prediction System streamline and isotach analyses, geostationary satellite imagery, and the tropical cyclone best-track information. Application of the Systematic Approach to the eastern and central North Pacific requires modifications in the Environment Structure and TC-Environment transitional mechanisms: (i) A Low Synoptic Pattern is defined; and (ii) a Weak Westerly Synoptic Region is defined in the Standard Synoptic Pattern. A four-year climatology of Synoptic Pattern, Regions, Pattern/Regions, and transitions is developed. The Standard Pattern and Dominant Ridge Region are the most common because of the dominance of the subtropical ridge in eastern and central North Pacific tropical cyclone motion. However, two subregions in the subtropical ridge with different tilts account for track direction variations from south of west to north of west within the Standard Synoptic Pattern. Storm tracks in each Pattern/Region combination reveal a characteristic track motion for each Pattern/Region. Subtropical Ridge Modification is found to be the most important transitional mechanism.

NAVY OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM (NOGAPS) ANALYSIS AND FORECAST CHARACTERISTICS OF EXTRATROPICAL CYCLOLYSIS OVER THE NORTH PACIFIC OCEAN

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Concentrated research has lead to improved understanding and prediction of extratropical cyclone development. Little research has been done on cyclolysis even though the decaying portion of a cyclone's life cycle, which begins after maximum intensity, poses maritime operational concerns. Numerical simulations with high resolution coupled air/sea models and several detailed case studies have lead to the hypothesis that friction parameterizations could have a profound affect on the accuracy of numerical analysis and prediction of decaying cyclones. In this study, analyzed and forecast characteristics of decaying cyclones over the North Pacific Ocean are related to the hypothesized importance of friction-induced cyclone spin down. It is found that many observed and forecast characteristics of cyclolysis, including gale area size and decay rate, vary according to the synoptic-scale conditions in which the cyclone exists. Furthermore, no evidence is found for the hypothesized relationship between cyclolysis and frictionally forced spin down in the analyzed and forecast model data. This result might be expected since friction spin down is parameterized based on analyzed and forecast winds over synoptic space and time scales. Therefore, it is concluded that over these scales other factors, which may include energy transfers due to barotropic processes, contribute in a major way to cyclone decay as portrayed in a global-scale numerical model.

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